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Life Cycle Costs for Disposal and Assured Isolation of Low-Level Radioactive Waste in Connecticut

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ABSTRACT

This document presents life cycle costs for a low-level radioactive disposal facility and a comparable assured isolation facility. Cost projections were based on general plans and assumptions, including volume projections and operating life, provided by the Connecticut Hazardous waste Management Service, for a facility designed to meet the State's needs. Life cycle costs include the costs of pre-construction activities, construction, operations, closure, and post-closure institutional control. In order to provide a better basis for understanding the relative magnitude of near-term costs and future costs, the results of present value analysis of out-year costs are provided.

EXECUTIVE SUMMARY

Introduction

All states and compacts that are developing new low-level radioactive waste (LLRW) disposal facilities have met strong resistance to the siting of those facilities. Much of that resistance has centered around concerns about the ability of the facilities to protect public health and safety by containing the radionuclides in the waste. These difficulties in siting LLRW disposal facilities have led to a proposal for a new approach to managing LLRW. In this approach the waste is placed in "assured isolation" (sometimes called "assured storage"), which uses man-made components similar to those used in LLRW disposal concepts. Assured isolation facilities are designed to accommodate continuing inspection and preventive maintenance inside the isolation units. This active inspection and maintenance can continue indefinitely after the operations phase of the facility, if desired. This is in contrast to disposal facilities, which are required to be backfilled upon closure to reduce the need for continuing active maintenance. Backfilling the disposal vaults precludes the option of inspection and maintenance inside the vaults.

Proponents of the assured isolation concept suggest it offers several major advantages over the usual LLRW disposal concepts, including reduced site characterization costs. When the present value of the life cycle cost is taken into account, this reduction in early expenses could be significant. This report describes comparative evaluations of the life cycle costs of assured isolation and disposal as methods for managing LLRW over the long term. The designs used as the basis of the cost analyses are representative of those thought to be generally acceptable to the public and protective of human health and the environment.

Conceptual Designs

Two conceptual facility designs form the basis for estimating life cycle costs: one for a disposal facility, and one for an assured isolation facility. Certain features are common to both facility designs. These include the waste to be emplaced, the period over which the waste is assumed to arrive at the facilities, the annual rates of waste receipt, and certain general characteristics of the disposal and isolation units. Generally, the common features are characteristic of facility designs that have been studied for disposal of LLRW in Connecticut. However, they do not necessarily represent what may eventually result in that state.

In both designs, the waste is placed in above-grade, reinforced concrete structures resembling vaults. Only the details and dimensions of the vaults differ. Both the disposal and assured isolation vaults have engineered earthen covers, although the assured isolation vaults do not have covers that are as elaborate as those for the disposal vaults. The total volume of LLRW to be disposed or isolated is 1,454,000 cubic feet, of which 214,000 cubic feet, or about 15 percent, is Class B and Class C waste. All waste is placed inside cylindrical, reinforced concrete canisters. The canisters are then placed inside the vaults. The waste was assumed to be received and emplaced over 50 years.

Options Analyzed

The life cycles of the disposal and assured isolation facilities analyzed were each divided into several phases to facilitate cost estimation. For the disposal facility, the phases are, in chronological order, preoperations, operations (the period when waste is being received at the facility), closure and postclosure, and institutional control. For assured isolation, the phases are preoperations, operations, and inspection and preventive maintenance. Since there are no specific plans to close the assured isolation facility, there is no phase in its life cycle comparable to the closure and postclosure phase for the disposal facility.

Several options related to the preoperations and to the institutional control or inspection and preventive maintenance phases of the waste management facilities were analyzed. These options include:

- Different costs for the preoperations phase. The different costs represent different levels of effort expended in site characterization and licensing.

- For the disposal facilities, different durations of the institutional control phase.

- For the assured isolation facilities, different durations of the inspection and preventive maintenance phase.

The various phases of the life cycles of the conceptual disposal and assured isolation facilities, and the options for some of those phases, resulted in the definition of 14 "cases" used in the analysis. The cases are defined in Chapter 2 of this report. Those 14 cases could be combined into 6 distinct combinations of cases, called scenarios, for estimating the life cycle cost of the conceptual disposal facility and 6 distinct combinations of cases for estimating the life cycle cost of the conceptual assured isolation facility.

Cost Estimates

Detailed estimates were made for the costs for each phase of the life cycles and for various options. For both types of facilities, for the preoperations phase the costs were principally for siting, site characterization, licensing and permits, and site preparation. For the operations phase, the greatest costs were for construction of the vaults, placement of the wastes, monitoring, and incentive and assistance payments to the host community. Major costs during the closure and postclosure phase at the disposal facility were for placing the final covers over the vaults and for monitoring. During the disposal facility's institutional control phase, the largest cost was for monitoring; during the assured isolation facility's inspection and preventive maintenance phase, the largest cost was for monitoring and inspecting the vault interiors.

It was assumed that enough money is collected during the operations phase to ensure that all activities following cessation of waste receipt can be paid for. Part of that money is needed to ensure that after the end of operations both the disposal facility and the assured isolation facility will have sufficient funds available to cover the cost of retrieving all waste, cleaning up contaminated soil at the site (disposal only), and placing some of those materials in another disposal or assured isolation facility, as appropriate. To prepare the life cycle cost estimates, it was assumed that monies put aside in a trust fund must be sufficient to pay for these activities any time following 100 years after the end of waste receipt.

Present Value Analysis

Present value analysis determines the amount of money that would have to be put aside now to have enough to pay for all activities anticipated to take place during a project's life cycle. One of the factors that must be taken into account when considering the cost of an activity that will not take place until a significant amount of time has elapsed is the effect of inflation. Another factor that must be considered is the potential earnings on money put aside now for paying expenses well into the future, called the return on investment.

One characteristic of present value analysis is that, whenever the return on investment is greater than inflation (as is usually the case), the present value of an activity decreases the further that activity occurs in the future. Thus, for most analyses where the annual return on investment exceeds the annual inflation rate, costs that are deferred make smaller contributions to the present value life cycle cost than those that are incurred early in the life cycle. For the present value calculations for activities through the end of waste receipt described in this report, the inflation rate used was 4 percent and the return on investment was 7.5 percent. With those parameters, a dollar spent 25 years in the future is equivalent to 44 cents set aside now (i.e., the present value of that dollar is 44 cents); a dollar spent 50 years in the future is equivalent to 19 cents now, and a dollar spent 100 years in the future is equivalent to less than 4 cents now; and beyond about 140 years in the future, the present value of a dollar is less than 1 cent.

Comparison of Present Value Life Cycle Costs

Present values for disposal scenarios range from $340 to $410 million while present values for assured isolation scenarios range from $330 to $350 million. Assuming a total waste volume of 1,454,000 cubic feet, the present value unit costs per cubic foot range from $520 to $630 for disposal and $510 to $530 for assured isolation. As a general rule, therefore, the present value life-cycle cost for assured isolation is the same or somewhat lower than for disposal.

Disposal relies primarily on site characteristics for waste isolation. Assured isolation, on the other hand, relies on active inspection and preventive maintenance of the engineered structure. It is anticipated that little if any site characterization would be necessary to ensure waste isolation. Because of this fundamental conceptual difference between the two approaches, it is to be expected that higher preoperations costs generally will be incurred for disposal (due to the extensive site characterization necessary to convince regulators of site licensability). These higher preoperations costs will influence the present value calculation more than costs incurred later in the life cycle.

Conclusion

Assured isolation may result in lower present value life cycle costs than disposal, depending on the assumptions made for costs during the preoperations phase. The advantage of lower costs at the start of the life cycle of typical assured isolation facilities is to some degree offset by higher costs during the operations phase, but not enough to cancel that advantage.

CONTENTS

FIGURES

TABLES

Life Cycle Costs for Disposal and Assured Isolation of Low-level Radioactive Waste in Connecticut

1. INTRODUCTION

1.1 Background

Most organizations that have attempted to site new (LLRW) disposal facilities have met strong resistance to the placement of those facilities. Much of that resistance has centered around concerns about the ability of the facilities to protect public health and safety by containing the radionuclides in the waste. Recently, a novel approach to managing LLRW has been proposed (Newberry 1995). In this approach the waste is placed in "assured isolation," which uses man-made components similar to those used in LLRW disposal concepts. The basis of the assured isolation concept is reliance on inspection and maintenance of the engineered facility rather than on sometimes uncertain site characteristics. Because they rely on inspection and preventive maintenance, assured isolation facilities require access to the interior of the isolation vaults before, during, and after waste emplacement; such access is not normally available after waste emplacement with disposal facilities. Specifically, in assured isolation the spaces between waste packages and vault walls are left open to allow movement of equipment and personnel involved in inspecting and maintaining the condition of the vaults. The assured isolation concept allows such inspection and maintenance to continue indefinitely.

The proponents of the assured isolation concept suggest it offers several major advantages over the usual LLRW disposal concepts. Because the concept relies on inspection of vault interiors and preventive maintenance, the public might accept an assured isolation facility more readily than a disposal facility. Increased acceptance could reduce the time required for siting such a facility and increase the number of siting options. Any resulting reduced site characterization costs (which for some compact facilities have approached $100 million) should lower the life cycle cost of the facility. When the present value of the life cycle cost is taken into account, this reduction in early expenses could be significant. Also, because access to the waste will be maintained for an indefinite period, technical advances can be used to help ensure waste isolation, even to the extent of removing the waste to treat and manage it in a different manner.

Assured isolation leaves open the possibility, among several others, of eventually closing a facility once there is high confidence in the overall system's ability to isolate waste. Any such closure would, of course, represent a conversion of the assured isolation facility into a disposal facility. It would require that all regulatory requirements for disposal in effect at that time be met and that approval of the appropriate regulatory agency be obtained.

1.2 Purpose

The purpose of this report is to assist in comparative evaluations of the life cycle costs of assured isolation and disposal as methods of managing LLRW over the long term. This report does not examine other issues regarding the relative merits of the two waste management methods, such as their acceptability to the public or their ability to protect the public or the environment. The designs used in the cost analyses are, however, representative of those thought to be generally acceptable and protective.

The waste volumes and characteristics used in this comparative analysis are similar to those that may require management in Connecticut. However, the conceptual facility designs and cost estimates are not intended to represent those that may ultimately result in that state.

This report presents the results of present value analyses of costs associated with the major life cycle phases of conceptual assured isolation and disposal facilities for LLRW. For some of those phases, several options for activities conducted during the phase were analyzed. In this report, the information on present values of costs is presented separately for each phase of the life cycle and (if applicable) for each option.

1.3 Overview

The conceptual designs and the major phases of the facility life cycles for which the present value life cycle costs were estimated are described in Chapter 2. Chapter 2 also defines the 12 plausible combinations of "cases"—6 combinations for disposal and 6 combinations for assured isolation—for which present value costs were estimated. Chapter 3 provides brief descriptions of how present value analyses are conducted and how unit costs for waste placement are estimated. Chapter 4 presents and discusses the estimated present value life cycle costs for a selected set of cases and, more briefly, for all plausible combinations of cases.

Appendix A gives brief descriptions of what each of the cost elements, or building blocks, for the cost estimates involves. Appendix B describes methods used to scale estimates of individual cost elements for the disposal and assured isolation facilities from those for a reference disposal facility. Appendix C presents major cost elements used in estimating the life cycle costs for a selected set of the cases described in Section 2.4. Appendix D presents detailed cost estimates for all cases.

2. CONCEPTUAL DESIGNS

This chapter describes the conceptual facility designs that form the basis for the comparative life cycle costs. It also discusses the concepts of operation for the facilities, including such details as the durations and levels of monitoring after all the waste has been emplaced. Because the present value of life cycle costs is influenced by the time in the life cycle when the costs are incurred, the concepts of operation influence the comparisons that are the subject of this report. This chapter concludes with descriptions of the twelve combinations of cost cases that were analyzed.

2.1 COMMON FEATURES

Certain features, shown in Table 2-1, are common to both facility designs. These include the waste to be emplaced, the period over which the waste is assumed to arrive at the facilities, the annual rates of waste receipt, and certain gross characteristics of the disposal and assured isolation units. Generally, these features are characteristic of waste and designs that have been studied for disposal of LLRW in Connecticut. However, they do not necessarily represent what may eventually result in that state.

For the purposes of this study, the facilities were assumed to operate full time, with staffs sized according to the waste receipt rates. In both designs, the waste is put in above-grade, reinforced concrete structures resembling vaults. Only the details and dimensions of the vaults differ, as described in Sections 2.2 and 2.3. The disposal units and assured isolation units have engineered earthen covers, although the isolation units do not have covers that are as elaborate as the disposal units (unless a decision were to be made later to convert the assured isolation facility into a disposal facility).

The total volume of LLRW to be disposed of or stored is 1,454,000 cubic feet, of which 214,000 cubic feet, or about 15 percent, is Class B and Class C waste. The waste acceptance criteria were assumed to be the same for disposal and assured isolation. All waste is placed, still in its shipping containers, inside cylindrical, reinforced concrete canisters that are approximately 9 feet high and 8 feet in diameter. These canisters can hold fourteen 55-gallon drums in two layers of seven drums each, a 96-cubic-foot box, or a 170-cubic-foot liner holding waste. Voids in the canisters are then filled and the canisters are placed inside the vaults. While the vaults described in this report might be used to accommodate large irradiated components from nuclear power plants, no decision on whether they would be appropriate for such use has been made at this time.

The waste was assumed to be received and emplaced over 50 years at the rates shown in Figure 2-1, with operations assumed to start in the year 2002. The waste was assumed to be received at a rate of 16,000 cubic feet per year from 2002 through 2007. Starting in 2008, when reactor decommissioning in Connecticut is expected to begin, and ending in 2039, when decommissioning is expected to end, an average waste receipt rate of 40,560 cubic feet per year was assumed.[*] From 2040 through 2051 (the last year the facilities receive waste), an average waste receipt rate of 5,000 cubic feet per year was assumed.

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[*] Subsequent to the preparation of these analyses, a decision was made to begin decommissioning one of the nuclear power plants in Connecticut in 1998 or 1999. The analyses have not been changed to reflect that decision.

Table 2-1. Common features of the assured isolation and disposal facility designs.

Feature	Description
Waste location	Above grade
Disposal units	Reinforced concrete vaults with engineered earthen covers[a]
Waste canisters	Reinforced concrete cylinders approximately 9 feet high and 8 feet in diameter
Waste volume	1,454,000 cubic feet (15 percent is Class B and Class C waste)
Waste emplacement rate	Shown in Figure 2-1

a. Earthen cover designs for assured isolation are generally different from those for disposal (see Sections 2.2.1 and 2.3.1).

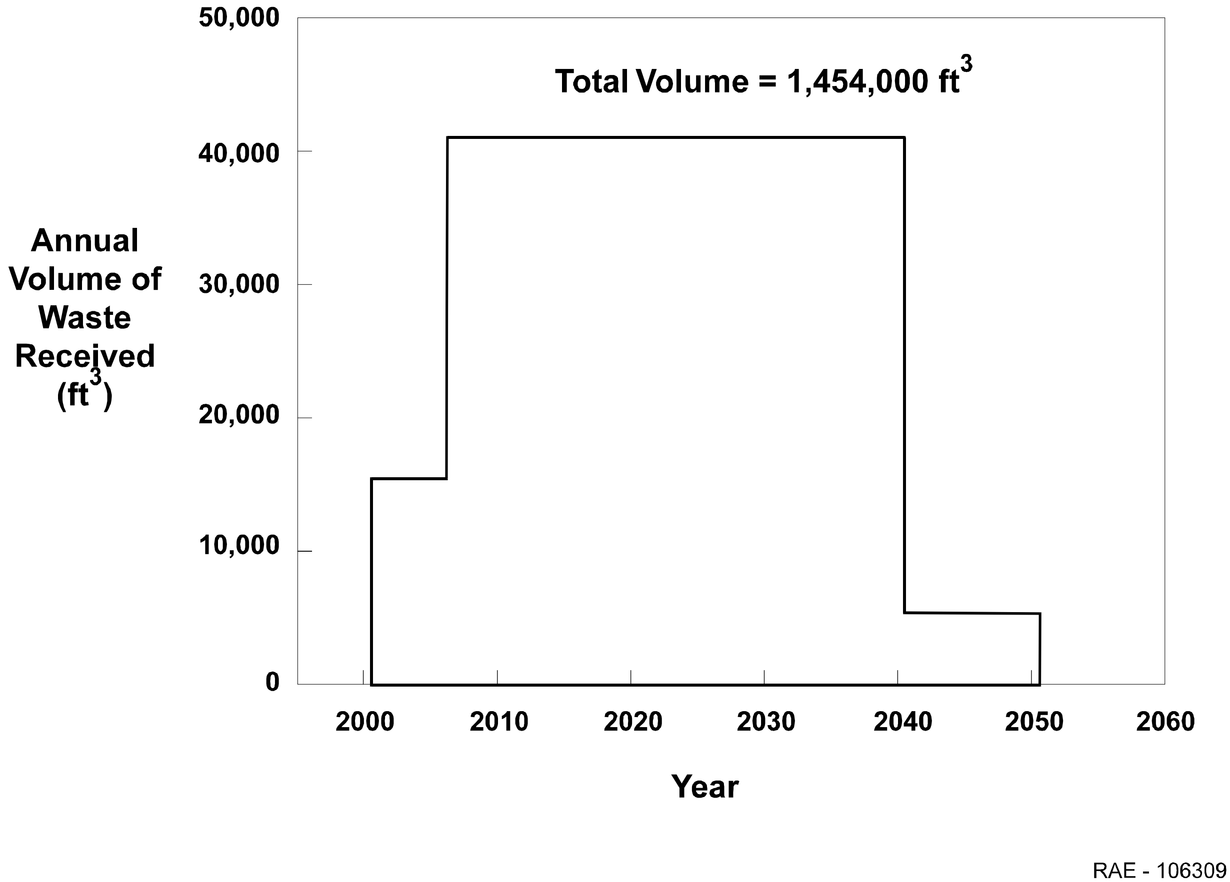

Figure 2-1. Waste receipt rates.

2.2 Conceptual Design For Disposal

The conceptual design for LLRW disposal involves placing concrete canisters in concrete vaults. Waste in its shipping containers is placed inside the canisters, grout is added to fill all the voids in the canisters, and the canisters are sealed. The canisters are then loaded through the open tops of the vaults before the roofs are built. When a vault is full, the spaces between and above the canisters are filled with gravel and the vault roof is constructed. Eventually, the vaults in a disposal unit are covered with an engineered earthen cover system. The system of concrete canisters, concrete vaults, and an earthen cover helps isolate the waste from the biosphere, and the cover protects the concrete vaults from the effects of temperature and moisture.

A single vault design is used for all three classes of LLRW. The interior of this vault is high enough to accommodate three layers of concrete canisters. If all of the waste is shipped in 55-gallon drums, the vault can accommodate almost 16,000 cubic feet of waste. The bottom layer of the canisters is placed on a 6-inch layer of gravel to help keep it above any water that may accumulate on the cell floor. The thickness of the gravel is included in determining the vault's interior height.

To satisfy regulatory requirements for their disposal, including the disposal depth requirement for Class C wastes, Class B and C wastes are only put in the lowest layer of canisters. The combination of the vaults and the canisters provides the 300 years of structural stability required for the Class B and C wastes. Therefore, all three classes of waste can be placed in the same vault.

Drains route any water that may reach the vault floors into collection tanks. These tanks are normally dry. If any water is detected in the tanks, it is sampled and analyzed for all potential contaminants.

Figure 2-2 is a perspective drawing of the vaults used in the disposal facility. Figure 2-3 is a plan view which shows the arrangement of the vaults in the larger of the two disposal units in the facility. Note that the vaults are constructed in pairs that are isolated from one another by an expansion joint. The two rows of vaults that make up the disposal unit are separated by an aisle to allow the use of a bridge crane to load the waste into the vaults. Vault walls are shown with various thicknesses. Generally, the outermost walls of the disposal unit are thickest to resist potential chemical attack from soil and water. Wall thickness is also determined by the span of the vault roof.

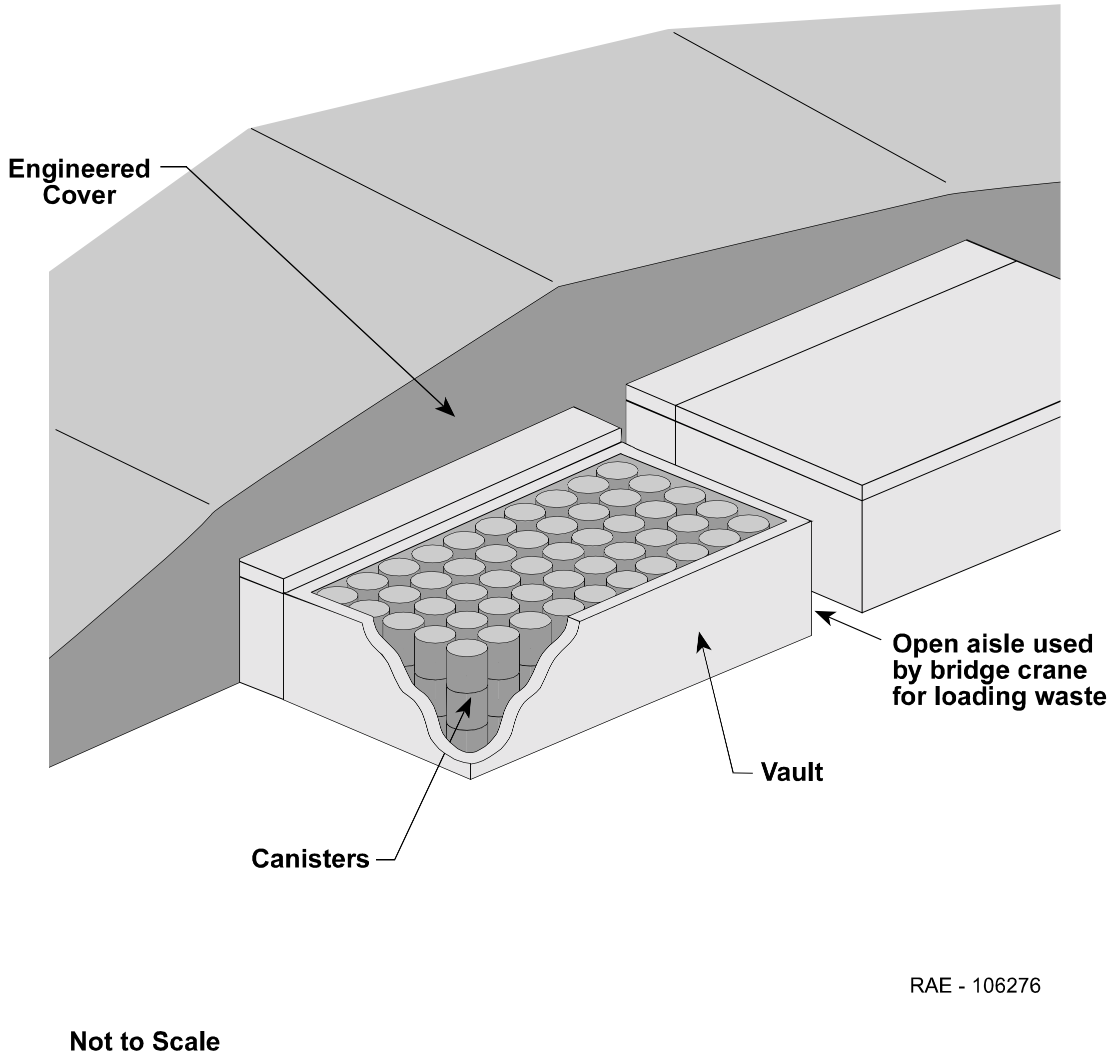

Figure 2-2. Perspective drawing of disposal vaults.

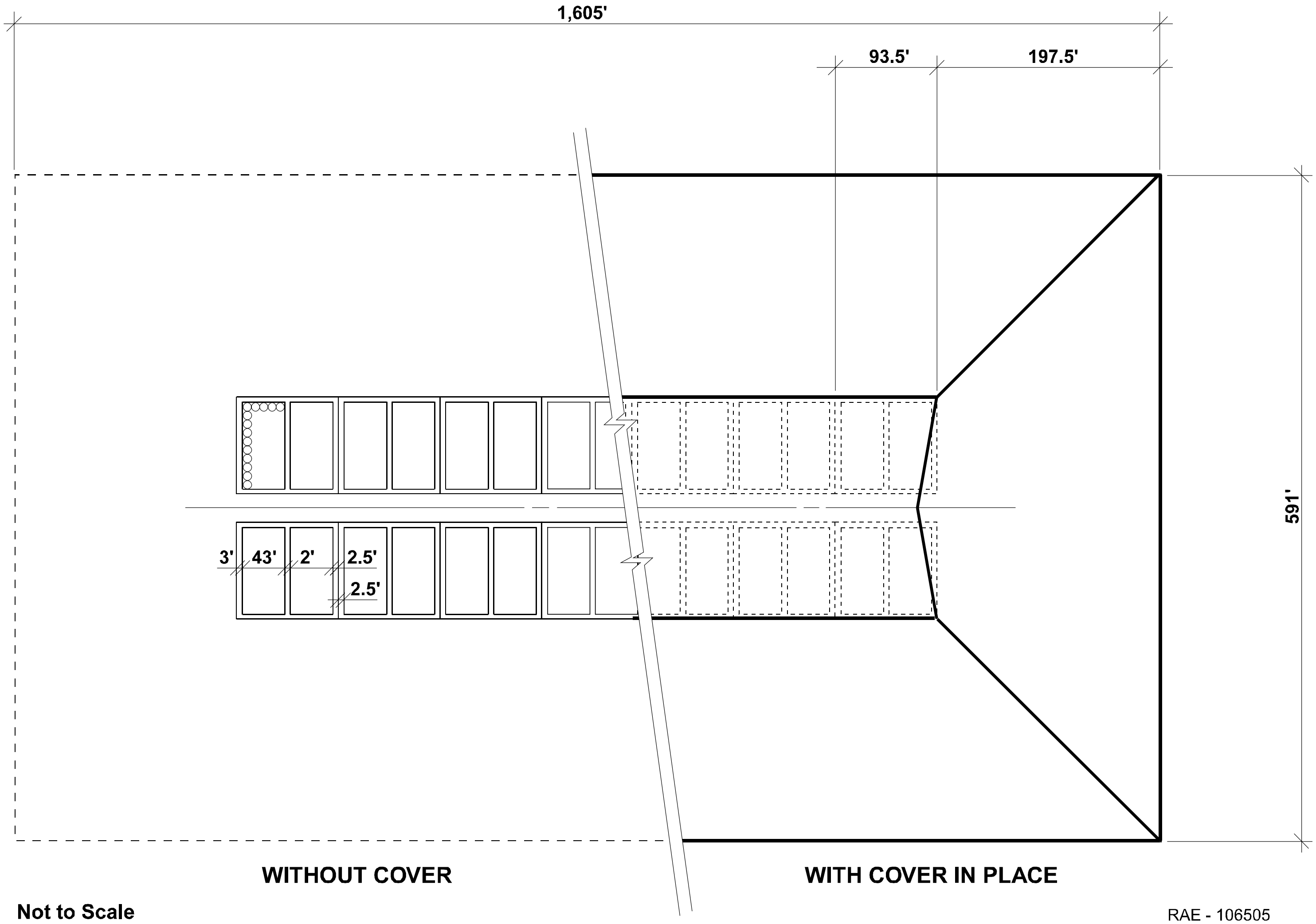

Figure 2-3. Plan view of the larger disposal unit.

Figure 2-4 is a vertical cross section of a disposal vault. The exterior of this vault measures about 92 feet long, 46 feet wide, and 37 feet high from the bottom of the foundation to the top of the lowest point on the roof. The interior of each vault is about 86 feet long, 43 feet wide, and 28 feet high.

Figure 2-5 shows the layout of the disposal facility. As mentioned above, the vaults in this design are arranged in two disposal units, one larger than the other. The larger unit contains 2 rows of 26 vaults each, while the smaller contains 2 rows of 20 vaults each. The area covered by the disposal facility, including a 400-foot wide buffer zone, totals 123 acres.

Earthen Covers—The final component of the disposal unit is the cover system. After each vault is filled, an interim cover is placed over it. The lower 3.5 feet of the interim cover are identical to the lower 3.5 feet of the final cover shown in Figure 2-6. The upper 4 feet of the interim cover are a temporary layer of soil which supports vegetation that helps reduce potential erosion and increases evapotranspiration to reduce water infiltration. The interim covers have the same slope over the tops of the vaults as the final cover but have a 50 percent slope at the sides of the vaults.

When the disposal facility is closed, the top 4 feet of the interim covers that are over the tops of the vaults are replaced with the materials that constitute the top 4 feet of the final cover shown in Figure 2-6. Around the sides of the vaults, native soil is placed to support the final cover with the shallow slopes shown in Figures 2-3, 2-4, and 2-5.

The layers of the final cover system and their functions, starting at the bottom of the cover and proceeding upward, are as follows:

- At least 6 inches of gravelly sand. The sand serves as a lower drainage layer to help divert away from the vaults any water that comes through the clay layer above. It also serves as bedding for the clay layer.

- Three feet of carefully compacted clay. The clay layer acts as a barrier that keeps precipitation from reaching the vaults.

- A layer of 60-mil, high-density polyethylene (HDPE). The HDPE layer serves as a barrier to precipitation.

- A layer of geotextile. The geotextile keeps the coarse gravel and cobble from damaging the HDPE layer.

- Two feet of coarse gravel and cobble. This layer serves as a major drainage pathway to divert precipitation away from the vaults. Water moving downward through the cover is stopped by the HDPE liner and clay layer and, because of the slope of the cover layers, runs off through the coarse gravel and cobble. The gravel and cobble layer also serves as a capillary break by preventing moisture from being drawn upward out of the clay layer (the clay layer must remain moist to serve as a barrier to precipitation), as a physical barrier to animal intrusion, and as a deterrent to plant root intrusion because it holds very little of the moisture necessary to support plant life.

- Six inches of pea gravel topped by a 6-inch layer of sand. The pea gravel and sand provide gradual changes in soil grain size to keep the soil in the top layer from moving down into the coarse gravel and cobble.

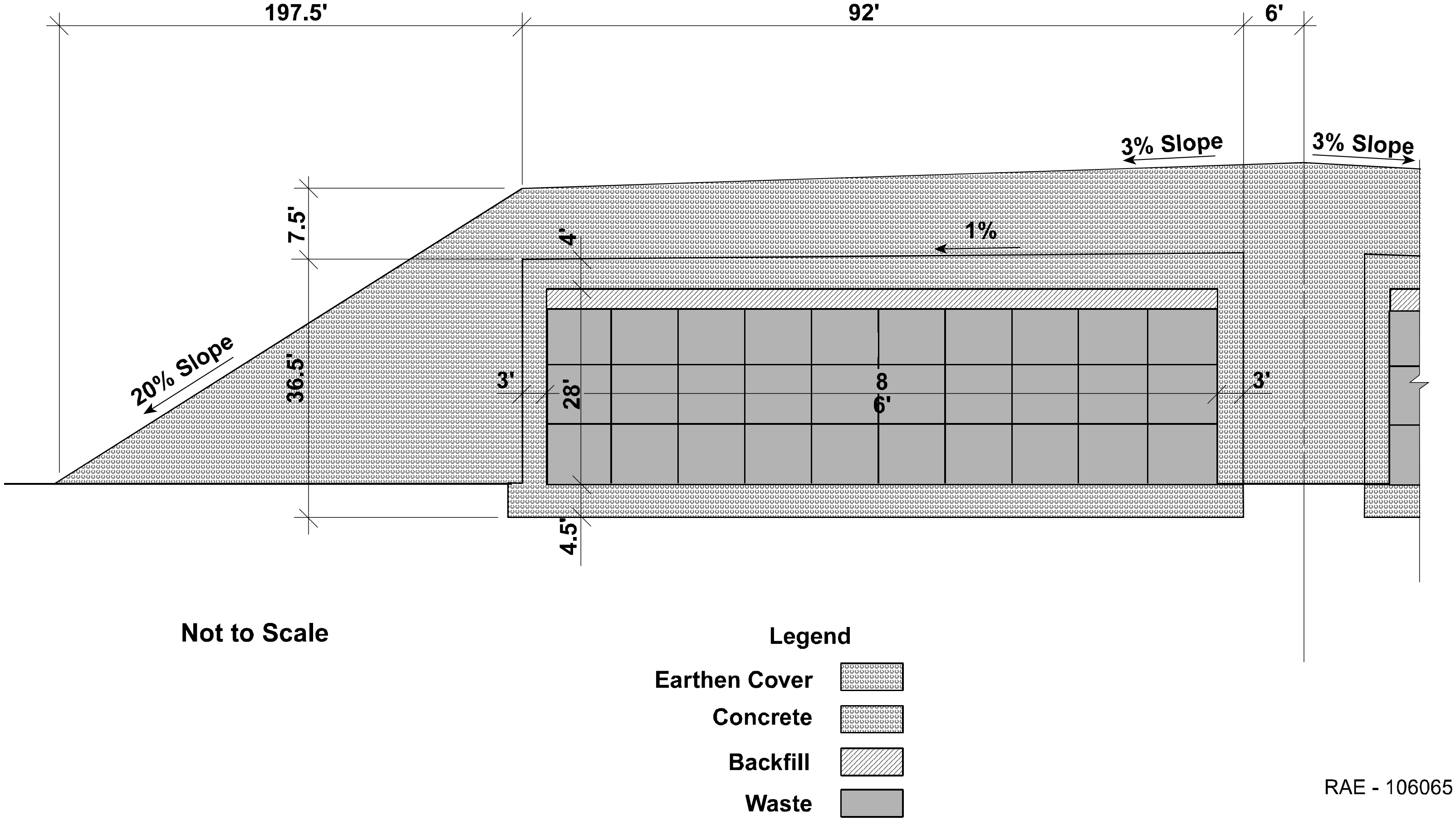

Figure 2-4. Vertical cross section of a disposal unit.

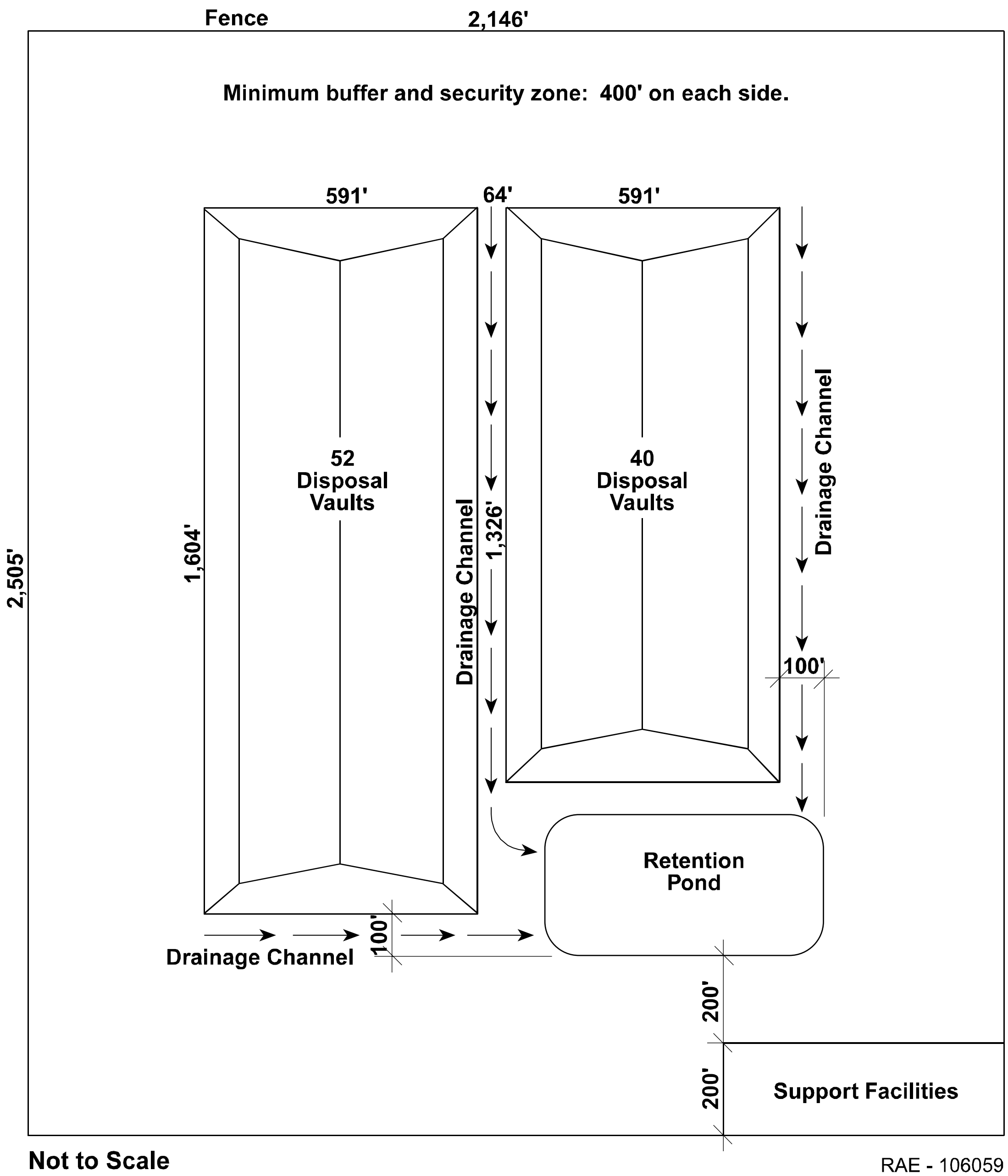

Figure 2-5. Layout of the disposal facility.

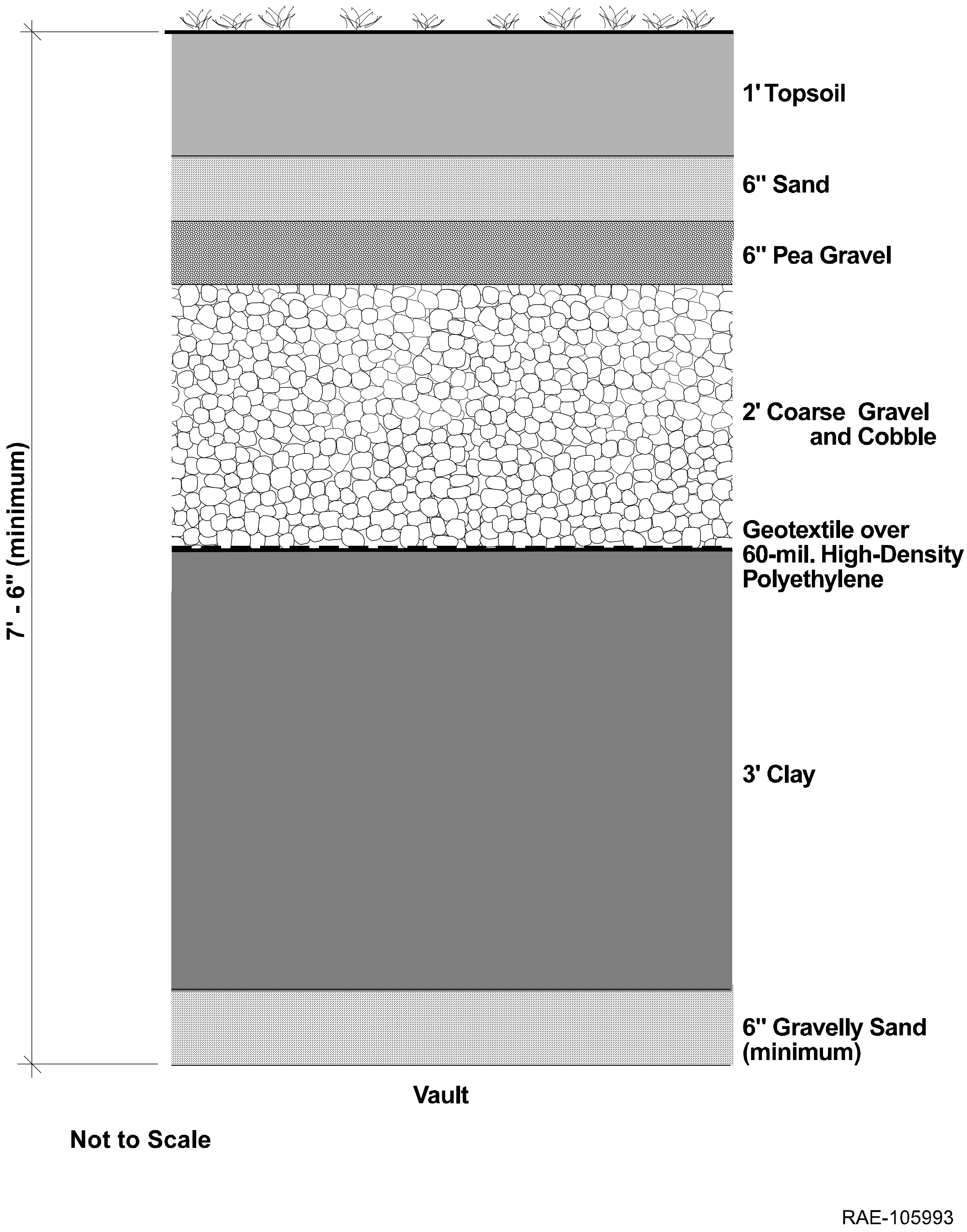

Figure 2-6. Final cover system for the disposal units.

- One foot of topsoil. The topsoil allows growth of short-rooted plants, such as grass, that prevent wind or water erosion of the cover. The vegetation on top of the cover also reduces, through transpiration, the amount of precipitation that the lower layers of the cover have to divert away from the vaults.

Immediately above the disposal vaults, the slope of the cover system is about 3 percent. This gradient encourages rainfall runoff without creating significant potential for erosion. The slope of the final cover system at the sides of the disposal vaults is 20 percent.

The disposal facility also includes a runoff retention pond to hold runoff from the disposal units. Water collected in the pond is analyzed and, if found to be uncontaminated, released to the environment. If the water in the retention pond is found to be contaminated, it is processed to remove contaminants and then released.

Surrounding the disposal units and retention pond is the buffer and security zone of at least 400 feet required by Connecticut regulations. Administrative and other support facilities are located within the buffer and security zone.

Life Cycle—The life cycle of the disposal facility includes preoperations, operations, closure and postclosure, and institutional control phases. The facility is located at a volunteer site. During the 5-year preoperations phase, the site for the disposal facility is selected and characterized, and the facility is designed and licensed. Some initial construction of support facilities occurs during the preoperations phase.

The facility's operations phase, during which all of the waste is received at the site, lasts 50 years. Waste arriving at the facility is disposed of as soon as it is received and placed in concrete canisters. As waste is accumulated in the disposal units, a program for monitoring for any releases from the disposal units, and from the waste canisters inside the disposal units, is maintained. The environment around the facility also is carefully monitored for any releases of contaminants. If any releases are detected, they would be appropriately remediated.

The disposal facility's closure and postclosure phase lasts 5 years. This phase begins with the end of waste receipt and involves closure and intense monitoring of the facility. Activities during this phase include removal of most support buildings and placement of the final covers over the vaults.

The closure and postclosure phase is followed by an institutional control phase, during which the radioactivity in the disposed waste decays significantly and the facility is monitored to detect releases of radioactive contaminants and signs of deterioration of the waste containment system. Figure 2-7 illustrates how the total radioactive content of typical Connecticut waste decays with time. Note that in 100 years the radioactivity decays to about 8 percent of its original value. In 500 years, it drops to less than 1 percent of its original value.

It was assumed that during institutional control, as confidence is gained in the performance of the facility, the monitoring and maintenance effort (and therefore the rate of expenditure) will be approximately halved at some point, and later halved again. Costs for two durations of institutional control were analyzed—100 years and 300 years (see Section 2.4). For the 100-year duration, it was assumed that the effort is halved 10 years after the start of institutional control and halved again 25 years after the start of institutional control. The corresponding points for the 300-year duration are 30 years and 75 years after the start of institutional control. The cutoff point for the cost analyses was the end of the institutional control phase.

Table 2-2 lists the major phases of the disposal facility life cycle.

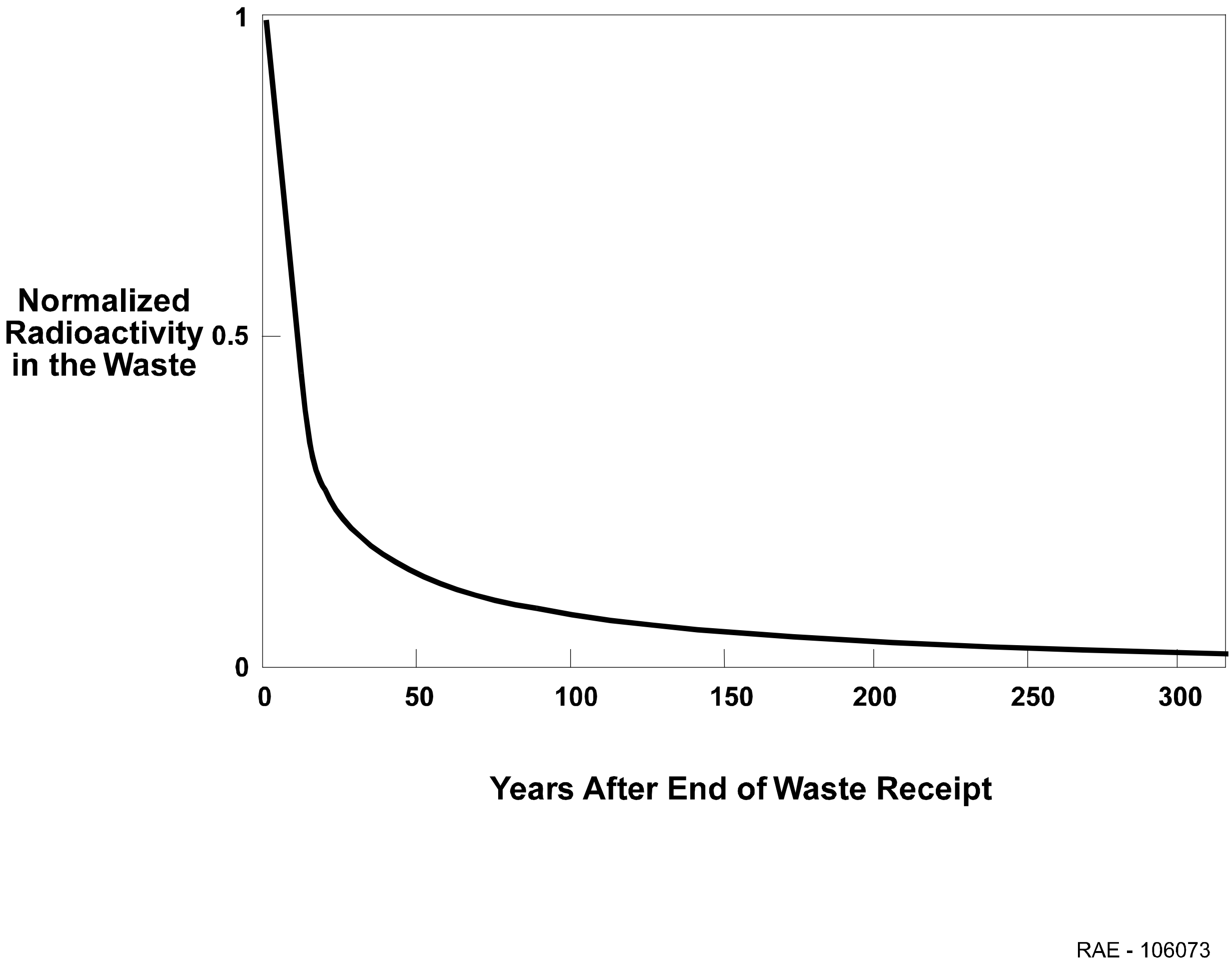

Figure 2-7. Decay of radioactivity in waste with time.

Table 2-2. Major life cycle phases of the disposal facility.

Phase	Duration (yr)	Major Activities
Preoperations	5	Site selection Site characterization Design Licensing
Operations	50	Waste placement Interim cover placement Intense monitoring
Closure and postclosure	5	Final cover placement Intense monitoring
Institutional control	100 or 300	Monitoring and maintenance

2.3 Conceptual Design For Assured Isolation

Like the disposal facility design, the assured isolation facility design involves placing concrete canisters in concrete vaults. However, in the assured isolation design, granular materials such as gravel or sand are used to fill any void spaces between the waste shipping containers and the canister walls. This feature facilitates retrieval of individual waste containers within the canisters.

Among other things, the design of the assured isolation facility does not preclude a subsequent decision to convert the facility into a disposal facility. Of course, any such conversion will depend on being able to meet the regulatory requirements for disposal in effect at that time and on getting approval from the appropriate regulatory agency.

To allow continual monitoring of the condition of the vaults, the assured isolation facility incorporates a remotely operated, mobile, visual inspection device. This device, which is equipped with a television camera, is used to check the vaults during the operations phase, and for as long after the end of operations as inspection and preventive maintenance continue. The device must raise the camera almost 30 feet above the vault floor and maneuver it horizontally about 25 feet over the top layer of waste canisters to inspect the vault roof. To accommodate the remotely operated camera, the design for the assured isolation vaults incorporates 3.5-foot-wide aisles between the waste canisters and the vault walls.

Drains route any water that may reach the floors of the vaults into collection tanks. These tanks are normally dry. If any water is detected in the tanks, it is sampled and analyzed for all potential contaminants.

Unlike the construction sequence for the disposal facility, the roofs of assured isolation vaults are constructed before waste placement begins, and the waste is emplaced from the sides of the cells. This sequence is primarily dictated by two differences between disposal and assured isolation. In the disposal facility designs, gravel is placed on top of the waste canisters when each vault is filled, serving as a lower form when the concrete roof is constructed. This cannot be done in the assured isolation design because the vault roof must be inspected from inside. Also, since there must be access to the vaults to inspect their interiors, the waste is loaded into the vaults through openings in the walls instead of through the roof.

A less complex earthen cover is placed over the assured isolation vaults after they are filled with waste. This cover protects the concrete from freezing temperatures and helps divert precipitation away from the vaults. Furthermore, if repair of the vault roofs becomes necessary, this cover is much easier to replace than the more complex cover placed over disposal vaults.

As mentioned, the condition of the vault walls, floors, and roofs is inspected using a remotely controlled wheeled or tracked device equipped with a television camera. Viewing a television monitor in a location removed from potential radiation from the waste, an operator uses the device to scan all areas of the walls and roof of each disposal vault, and all visible areas of the vault floor. Any anomalous conditions observed are investigated further. The estimated cost for this inspection process does not include costs for investigations of anomalous conditions, since their frequency and nature are difficult to predict.

If in the future it is decided to convert the assured isolation facility into a disposal facility, and if the facility meets the regulatory requirements in effect for disposal at that time, closure features that ensure continued protection of public health and safety will be designed based on the actual record of the facility's performance. These features could be significantly different from anything now conceived of; however, for the purpose of this cost comparison, it was assumed that the spaces between the waste canisters and the interior vault walls would be filled with pea gravel, and that the inspection access portals from the central aisle into the vaults would be replaced with concrete walls. It also was assumed that the covers over the isolation units would be improved to be the same as the covers for the disposal facility (see Figure 2-6) and that the assured isolation facility would have to be licensed as a disposal facility.

The assured isolation facility design uses a single vault design for all three classes of LLRW. The interior of this vault is high enough to accommodate three layers of concrete canisters. If all of the waste is shipped in 55-gallon drums, the vault can accommodate almost 16,000 cubic feet of waste. To satisfy regulatory requirements in the event a decision is made to convert the assured isolation facility into a disposal facility, Class B and C wastes are only put in the lowest layer of canisters.

To allow future reductions in the inspection and preventive maintenance effort for certain vaults which may be justified after Class A waste has undergone radioactive decay for 100 years, the Class B and C wastes are used to fill the entire lowest layers of a few vaults. Because there is so little Class B and Class C waste, placing the waste this way allows some vaults to be used only for isolation of Class A waste. Should the assured isolation facility be converted into a disposal facility some day, placing Class B and C wastes in the lowest layer of canisters will ensure that the disposal depth requirement for Class C wastes will be satisfied. Also, the combination of vaults and canisters will provide the 300 years of structural stability required for Class B and C wastes.

Each vault contains a sump at a low point in the floor to collect any water that may enter the vault. The sumps are normally dry. If any water is found in a sump during inspection of the vault interior, it is sampled and analyzed for all potential contaminants.

Figure 2-8 is a perspective drawing of the vaults used in the assured isolation facility. Figure 2-9 is a plan view that shows the arrangement of the vaults in the larger of the two isolation units in the facility. This unit contains 52 vaults. The vaults are separated by a 20-foot-wide aisle into 2 rows of 26 vaults each. Note that the vaults are constructed in pairs that are isolated from one another by an expansion joint.

Figure 2-10 is a vertical cross section of an assured isolation facility vault. The exterior of this vault measures about 99 feet long, 35 feet wide, and 37 feet high from the bottom of the foundation to the top of the lowest point on the roof. The interior of each vault is about 93 feet long, 50 feet wide, and 28 feet high. Each vault can contain up to 150 concrete canisters configured in 3 layers of 50 each. These layers are placed in the center of the cell to create the 3.5-foot-wide aisles needed for the inspection equipment. Additionally, rather than being placed on a gravel bed (as is done in the disposal vaults), the bottom layer of canisters is placed directly on the cell floor. The assured isolation vaults do not have a gravel bed because any water on the cell floor would be detected during inspection and the conditions causing it would be quickly corrected.

Figure 2-11 shows the layout for the assured isolation facility. As in the design for the disposal facility, the vaults are arranged in two isolation units, one larger than the other. Also as with the disposal facility, the larger unit contains 2 rows of 26 vaults each, while the smaller unit contains 2 rows with 20 vaults each. The design reserves enough land to accommodate the larger earthen covers for conversion to disposal. The total site area is about 136 acres.

Earthen Covers—Figure 2-12 shows the cover system for the assured isolation units. The layers of this system and their functions, starting at the bottom and proceeding upward, are as follows:

- At least 6 inches of gravelly sand. The gravelly sand serves as a lower drainage layer to help divert away from the vaults any water that comes through the clay layer above. It also serves as bedding for the clay layer.

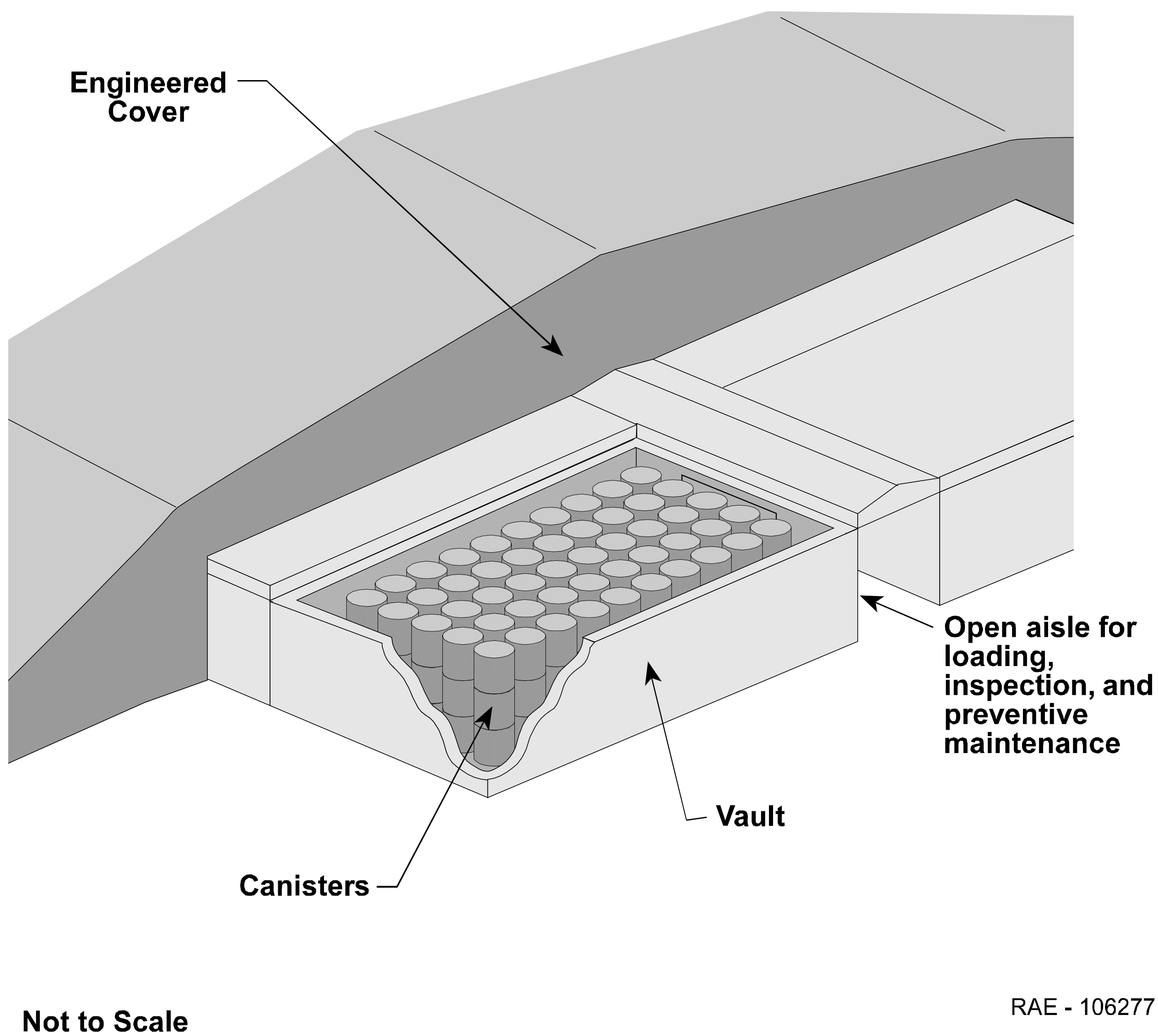

Figure 2-8. Perspective drawing of assured isolation vaults.

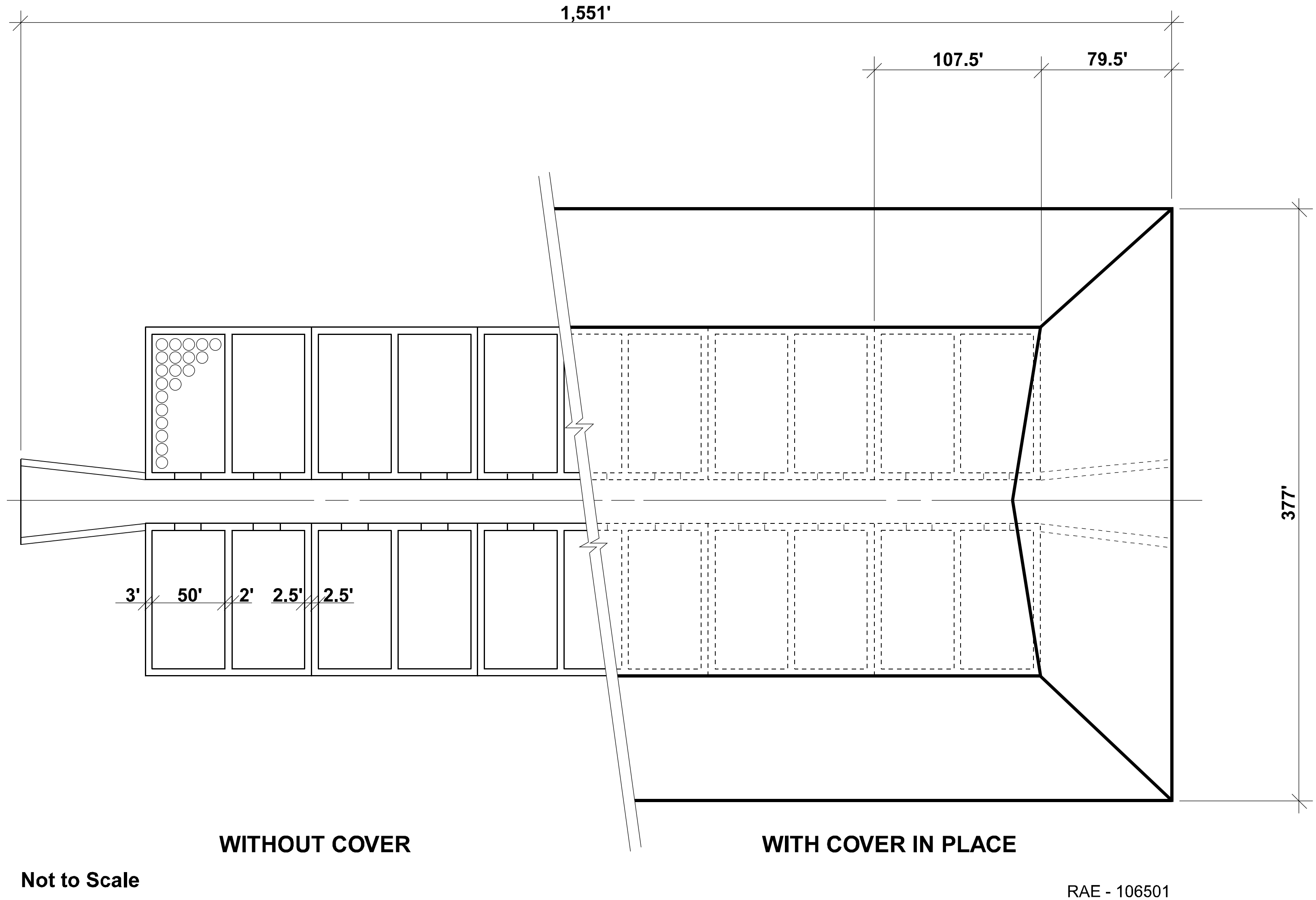

Figure 2-9. Plan view of the larger assured isolation unit.

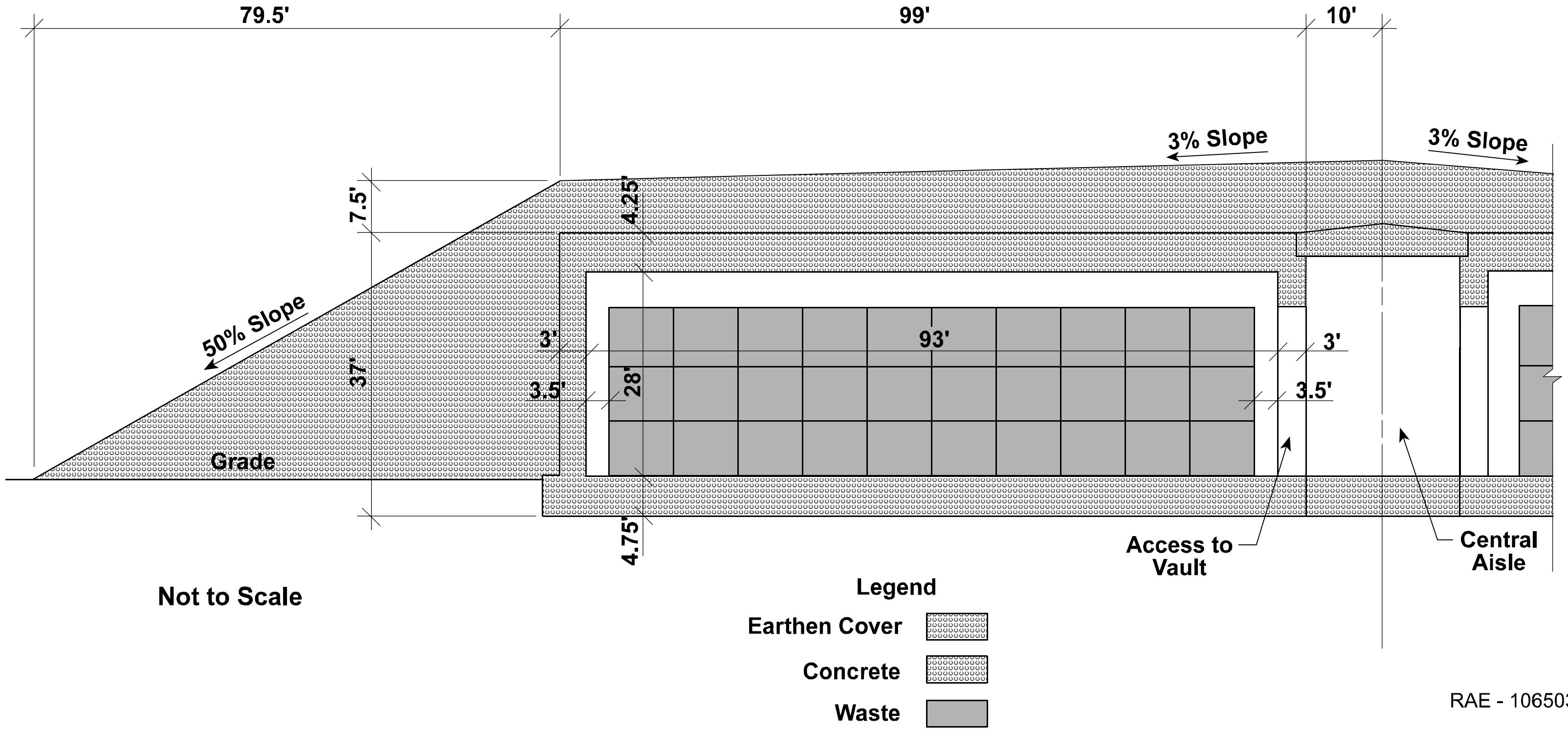

Figure 2-10. Vertical cross section of an assured isolation unit.

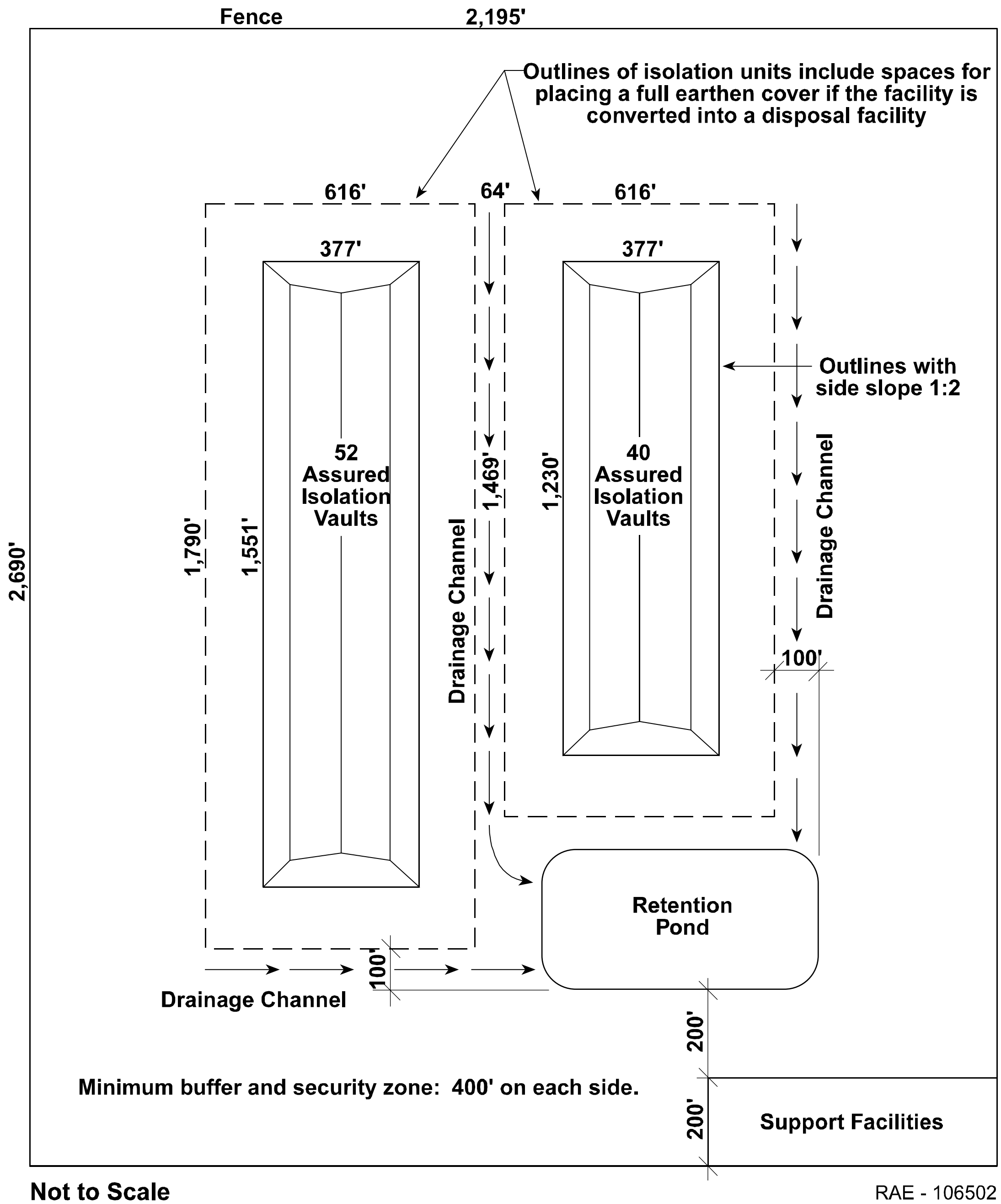

Figure 2-11. Layout of the assured isolation facility.

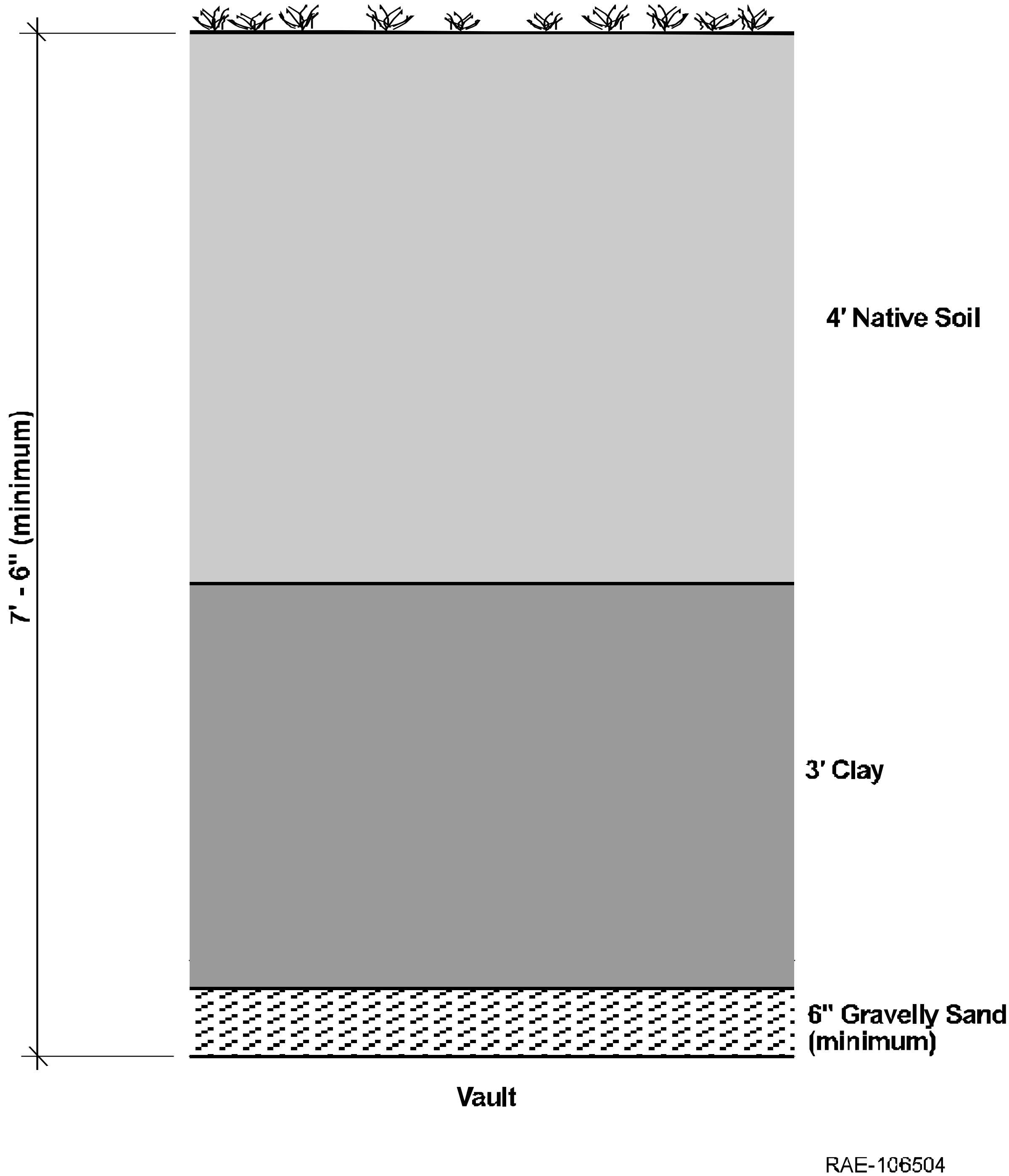

Figure 2-12. Cover system for the assured isolation units.

- Three feet of carefully compacted clay. The clay acts as a barrier that keeps precipitation from reaching the vaults.

- Four feet of native soil. The soil allows growth of short-rooted plants, such as grass, that prevent wind or water erosion of the cover. It also protects the clay from freeze-thaw cycles. The vegetation on top of the cover also reduces, through transpiration, the amount of precipitation that the clay and sand layers of the cover have to divert away from the vaults.

The cover shown in Figure 2-12 is sufficiently deep to protect the concrete vaults from freeze-thaw temperature cycles in Connecticut and to help prevent intrusion of precipitation and burrowing animals into the vaults, canisters, and waste. The slope of the covers over the isolation vaults is 3 percent, the same as the slope of the covers over the disposal vaults. The 50-percent cover slope at the sides of the isolation vaults is the same as that at the sides of the disposal vaults when the interim covers are in place. In case it is later decided to convert the assured isolation facility to a disposal facility, the site design leaves enough space to build covers over the isolation vaults that have the same thickness and slopes as those in the disposal facility design.

The assured isolation facility includes a runoff retention pond and 400-foot-wide buffer and security zone similar to the disposal facility. Water collected in the pond is analyzed, and if found to be uncontaminated, released to the environment. If the water in the retention pond is found to be contaminated, it is treated to remove the contaminants and then released. As with the disposal facility design, administrative and other support facilities are located in the buffer and security zone.

Life Cycle—The life cycle of the assured isolation facility includes 5-year preoperations and 50-year operations phases identical to those for disposal. As waste is accumulated in the isolation units, inspection of emplaced waste canisters and their surrounding vaults begins. Any potential impairment of the integrity of the canisters or vaults is remedied. Also, monitoring for any releases of radioactivity from the canisters, primarily by analyzing any water in the vaults, is conducted. The environment around the isolation units and the facility is also monitored for any releases of radionuclides. Because this monitoring is less important in demonstrating that the facility is performing as desired, however, it is generally conducted at a lower intensity than at the disposal facilities.

Since the assured isolation facility is not closed when waste receipt ends, its life cycle has no phase comparable to the closure and postclosure phase for disposal. Support facilities not needed for continued inspection and preventive maintenance are removed at the end of the operations phase.

For the purpose of the cost analyses, inspection and preventive maintenance at the assured isolation facility were assumed to continue at some level after waste stops arriving. As occurs in disposal, the radioactivity in the waste continues to diminish due to radioactive decay during the post-operations inspection and preventive maintenance phase (see Figure 2-7). Initially, inspection and preventive maintenance are assumed to continue at half the level maintained prior to the end of operations. One hundred years after the end of operations, inspection and preventive maintenance at vaults containing only Class A waste are discontinued, and the corresponding effort at the other vaults is reduced by half. At the same time, it was assumed that the level of effort for site monitoring and all other site efforts is also reduced by about half. (Note that these intervals are significantly longer than those for a disposal facility.) Later, if it can be demonstrated that public health and safety will be protected and if all appropriate regulatory agencies approve, inspection and preventive maintenance can end. Two durations of inspection and preventive maintenance were analyzed: 300 years and 500 years. While inspection and preventive maintenance could continue longer, the cost analyses did not cover durations beyond 300 years or 500 years.

Table 2-3 lists the major phases of the assured isolation facility life cycle.

Table 2-3. Major life cycle phases of the assured isolation facility.

Phase	Duration (yr)	Major Activities
Preoperations	5	Site selection Site characterization Design Licensing
Operations	50	Waste placement Cover placement Inspection Monitoring
Inspection and preventive maintenance	300 or 500	Inspection Preventive Maintenance Monitoring

2.4 Options Analyzed

In conjunction with the conceptual designs for disposal and assured isolation, options related to the development and operation of the waste management facilities were analyzed. Generally, these options included:

- For the preoperations phase, different levels of effort expended to characterize the site and obtain licenses.
- For the disposal facility, different durations of institutional control.
- For the assured isolation facility, different durations of inspection and preventive maintenance following the end of waste receipt.

Present value cost estimates are given in this report for many distinct cases. Each case is designated by an alpha-numeric code which indicates whether a disposal facility or an assured isolation facility is represented, what life cycle phase is represented, and which of the several options, if applicable, for that life cycle phase is represented. For example, the code D1B indicates that the case is for a disposal facility, for the first (preoperations) phase, and for costing option B.

The cases analyzed are as follows:

DISPOSAL

Preoperations Phase

Case D1A: This case is based on the methods used in NY 1995 and RAE 1992. The costs tend to be optimistically low compared to recent experience.

Case D1B: This case is based on an estimate of the average recent experience for preoperations costs in the U.S. Full characterization of a single site is assumed.

Case D1C: This case is also based on recent experience, but with full characterization of two sites.

Operations Phase

Case D2: This case represents operations at the disposal facility.

Closure and Postclosure Phase

Case D3: This case represents closure and postclosure activities at the disposal facility.

Institutional Control Phase

Case D4A: This case represents institutional control lasting 100 years.

Case D4B: This case represents institutional control lasting 300 years.

ASSURED ISOLATION

Preoperations Phase

Case I1A: This case represents preoperations activities that do not include site characterization because the assured isolation inspection system is designed to preclude release of contamination to the site.

Case I1B: This case is the same as Case I1A, except that limited or confirmatory drilling and groundwater characterization at the site are added.

Case I1C: In this case, the costs for several preoperations cost elements from Case D1A are used for the site development and for the licensing and permitting cost elements. They include costs for site development, environmental assessment and license application, licensing, and permits. This case represents a full site characterization and licensing process comparable to that for a disposal facility, as represented by the preoperations cost in Case D1A. (The licensing process, however, need not depend on site characteristics.)

Operations Phase

Case I2A: This case represents operations at the assured isolation facility, without groundwater monitoring.

Case I2B: This case is the same as for Case I2A, except that a cost for groundwater monitoring is added.

Inspection and Preventive Maintenance Phase

Case I3A: The case represents inspection and preventive maintenance with cost estimation ending 300 years after the end of operations.

Case I3B: This case represents inspection and preventive maintenance with cost estimation ending 500 years after the end of operations.

Figures 2-13 and 2-14 indicate which combinations of the preceding situations are plausible for disposal and assured isolation, respectively. The combinations joined by a series of arrows are plausible. There are six plausible combinations for disposal and six plausible combinations for assured isolation.

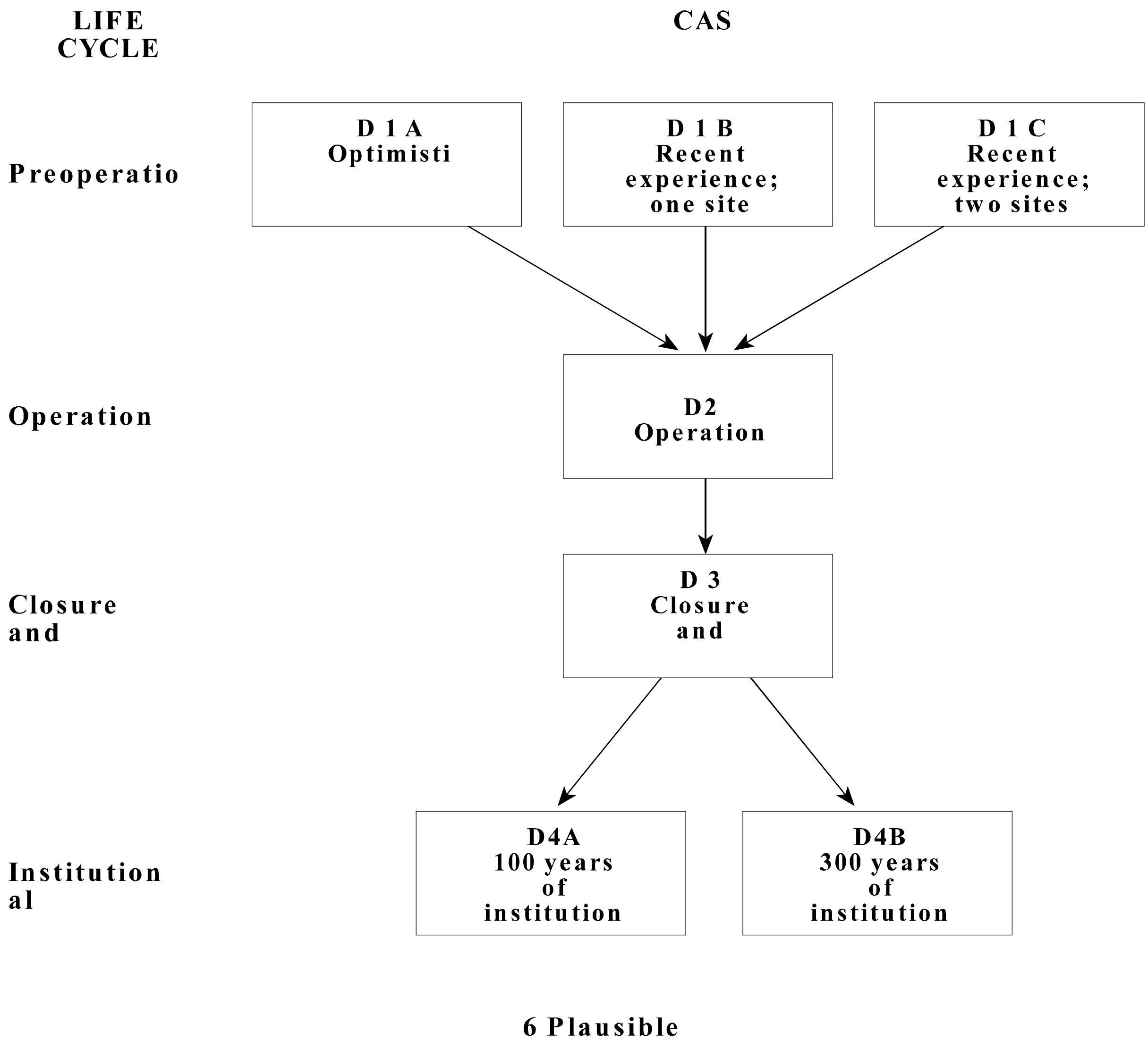

Figure 2-13. Cases for disposal.

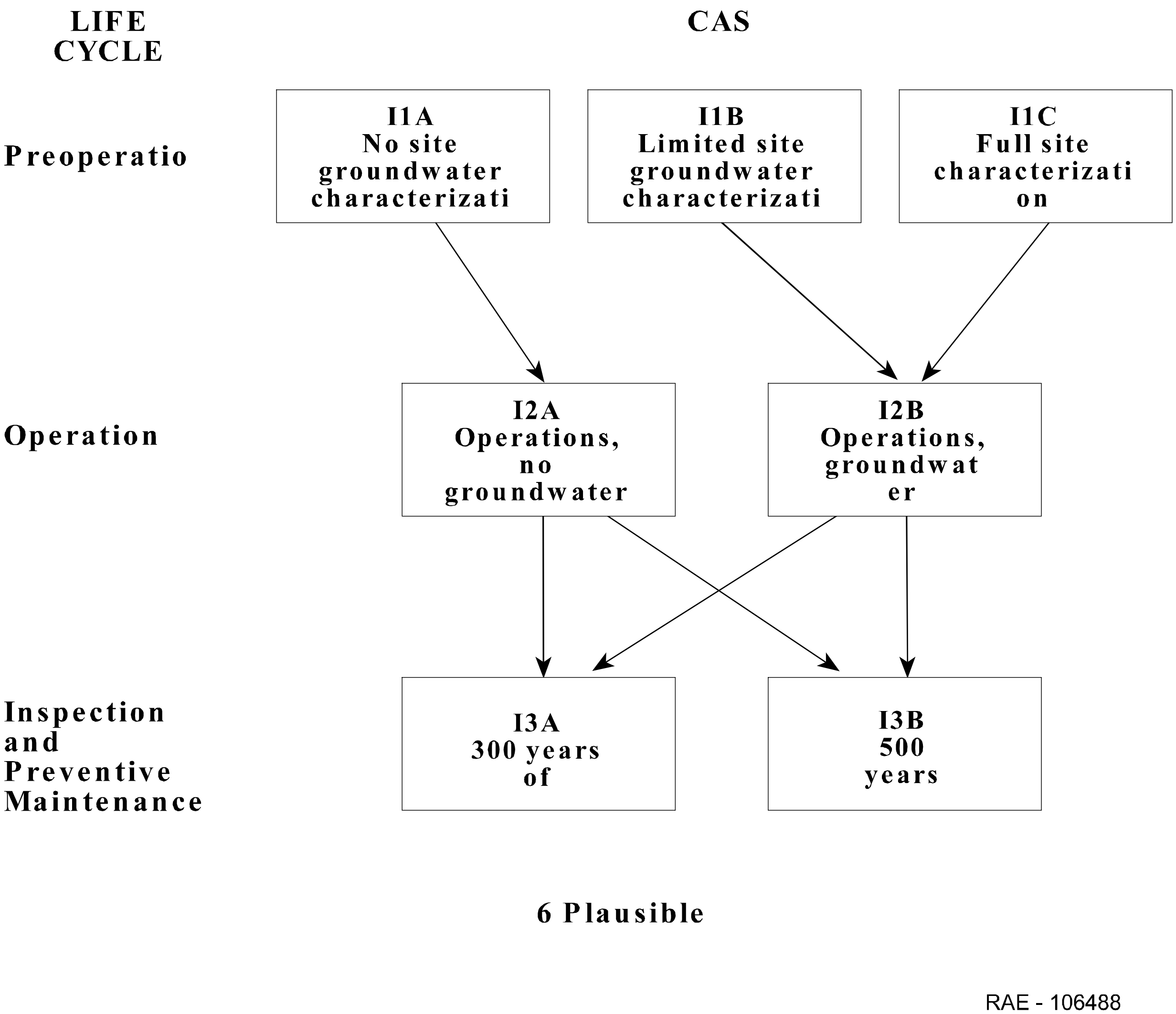

Figure 2-14. Cases for assured isolation.

3. PRESENT VALUE ANALYSIS

3.1 General Present Value Calculations

There are generally three methods for calculating estimates of costs of multi-year projects:

- Constant Value, which is the cost if the entire project was executed and paid for in a certain year, usually the current year. Costs are calculated for each year of the project as though the expenses are being paid in the designated year and then summed.

- Current Dollar, in which the effect of future inflation is accounted for on a year-by-year basis before summing the estimates of annual costs.

- Present Value, in which the effects of both inflation and the time value of money are accounted for on a year-by-year basis before summing the estimates of annual costs.

The first two methods ignore important aspects of the effects of time on long projects, so the present value method is used in this analysis of life cycle costs. It is the method usually chosen for use in comparing costs of alternative approaches to a specific objective where the magnitudes or timing of expenditures differ depending on the alternative.

Present value analysis determines the amount of money that would have to be put aside now to have enough to pay for all activities anticipated to take place during a project's life cycle. The effect of inflation is one of the factors that must be taken into account when considering the cost of an activity that will not take place until a significant amount of time has elapsed. Another factor that must be considered is the net potential earnings on deferred expenses or on money put aside now for paying expenses well into the future, called the return on investment. The following paragraphs help illustrate the interaction between inflation and return on investment and how they influence the present value of any activity that will take place in the future.

The return on investment has a significant impact on the results of present value analyses. The 7.5-percent annual return on investment used in these analyses to calculate the present value of costs incurred during the preoperations and operations phases is considered consistent with the cost of public borrowing during a period when inflation is at the 4-percent annual level that was also assumed for the analyses. A different return on investment, 6 percent, was used in calculating the present value of activities after the end of waste receipt. This lower return was chosen to be consistent with rules proposed by the U.S. Nuclear Regulatory Commission for funding of post-operations activities at commercial power reactors (NRC 1997). The lower return on investment represents a conservative approach to estimating how much money must be collected to ensure there will be sufficient funds for later activities. The net effect of using the 6-percent return on investment is to raise the present values of activities conducted after the end of operations, compared to what would have been calculated if the 7.5-percent rate of return had been used.

Suppose it is known that a certain item at the assured isolation or disposal facility, such as a wrench, must be purchased 30 years in the future. (The item could just as well be a bulldozer, a truck, an hour of the time of a watchperson, or the cost of a laboratory analysis of a groundwater sample.) If the present cost (in 1996 dollars) of the wrench is $10, the cost 30 years from now, in the year 2026, can be expected to be higher due to inflation. At the assumed rate of inflation of 4 percent per year, the wrench, when purchased 30 years from 1996, will cost about $32.40 in 2026 dollars. Figure 3-1 illustrates the effect of inflation on the cost of the wrench. However, if the $10 that could be used to purchase the wrench in 1996 is invested in

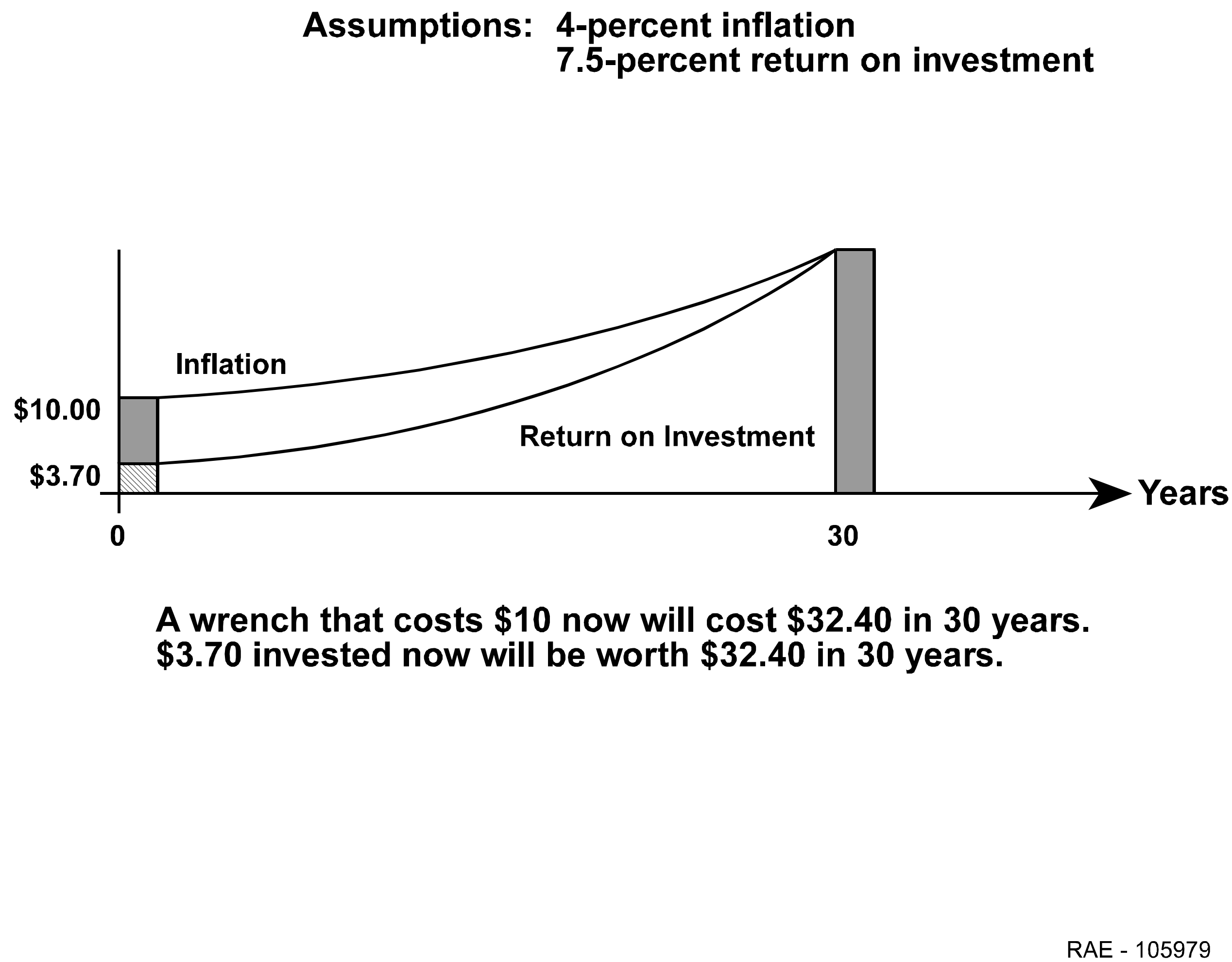

Figure 3-1. Present value illustration.

something that will yield a return on investment of 7.5 percent a year over the next 30 years, that $10 will be worth about $87.50 in 2026. Using an assumed 4-percent inflation and 7.5-percent return on investment, the 1996 present value of the wrench to be purchased in 2026 is the projected cost in 2026 ($32.40) divided by the value in 2026 of the $10 invested in 1996 ($87.50), times the present cost of the wrench ($10). This calculation gives a present value of about $3.70. Figure 3-1 illustrates that the present value of the wrench to be purchased in 2026 is the amount that would have to be invested in 1996 at a 7.5-percent rate of return to be able to buy the wrench 30 years later if the price of the wrench were to increase at 4 percent per year.

If it had been assumed that the facilities were privately funded, the return on investment for the preoperations and operations phases would have been assumed to be higher because private companies generally have to borrow money at higher interest rates and have to pay corporate income taxes on profits. The result of an assumption of private funding would be to exaggerate the effects of the present value analysis on costs for those phases, further reducing the present values of costs expected to be incurred in the distant future. For example, with a 10 percent return on investment the preceding calculation would yield a present value for the wrench of about $1.90.

Present value analysis is used to compare life cycle costs of projects to help identify projects that are economically most favorable over a defined period of time. For many projects, such as road improvements or harbor dredging, there is a readily identifiable monetary return for the money spent on the work. For other projects, such as those involving environmental protection or improvements in safety features, the monetary return may be harder to define. The enhanced protection of public health and safety that will result from building a LLRW disposal or assured isolation facility is a major benefit though, even if it is difficult to express in monetary terms. For this comparison, it was assumed that the disposal facility and the assured isolation facility would begin operations at the same time, and thus that the benefits they provide would be essentially the same. This assumption allowed the comparison to proceed solely on the basis of the present values of the costs of these two facilities.

One of the concerns sometimes expressed about present value analyses relates to uncertainties in the predicted inflation rate and return on investment. The last few decades have demonstrated that these parameters can vary widely over the time frames of interest in this comparison. However, it is the <u>difference</u> between these two parameters that determines the present value of a future cost for a particular project; that difference, known as the real rate of return, is much less volatile than either of its two individual components.

One characteristic of present value analysis is that, whenever the return on investment is greater than inflation (i.e., a positive real rate of return), the present value of an activity decreases the further that activity occurs in the future. If the wrench used in the example above is to be purchased 40 years in the future instead of 30 years, the present value of the wrench would be about $2.70. Thus, for most analyses where the annual return on investment exceeds the annual inflation rate, costs that occur later make smaller contributions to the present value life cycle cost than those that are incurred early in the life cycle.

The higher the assumed real rate of return, the less impact expenditures in the distant future have on present value costs. Therefore, the assumed real rates of return used in the calculations can influence the relative present value life cycle costs of disposal and assured isolation, depending on when particular expenditures are made.

As noted above, for the present value calculations described in this report, the inflation rate used was assumed to be 4 percent and the return on investment was assumed to be 7.5 percent for costs incurred during the preoperations and operations phases. Figure 3-2 shows how this combination of return on investment and inflation reduces the impact of costs that are incurred in the future. The figure indicates the present value of a dollar spent at various times in the future. For example, a dollar spent 25 years in the future is equivalent to 44 cents spent now, a dollar spent 50 years in the future is equivalent to 19 cents now, and a dollar spent

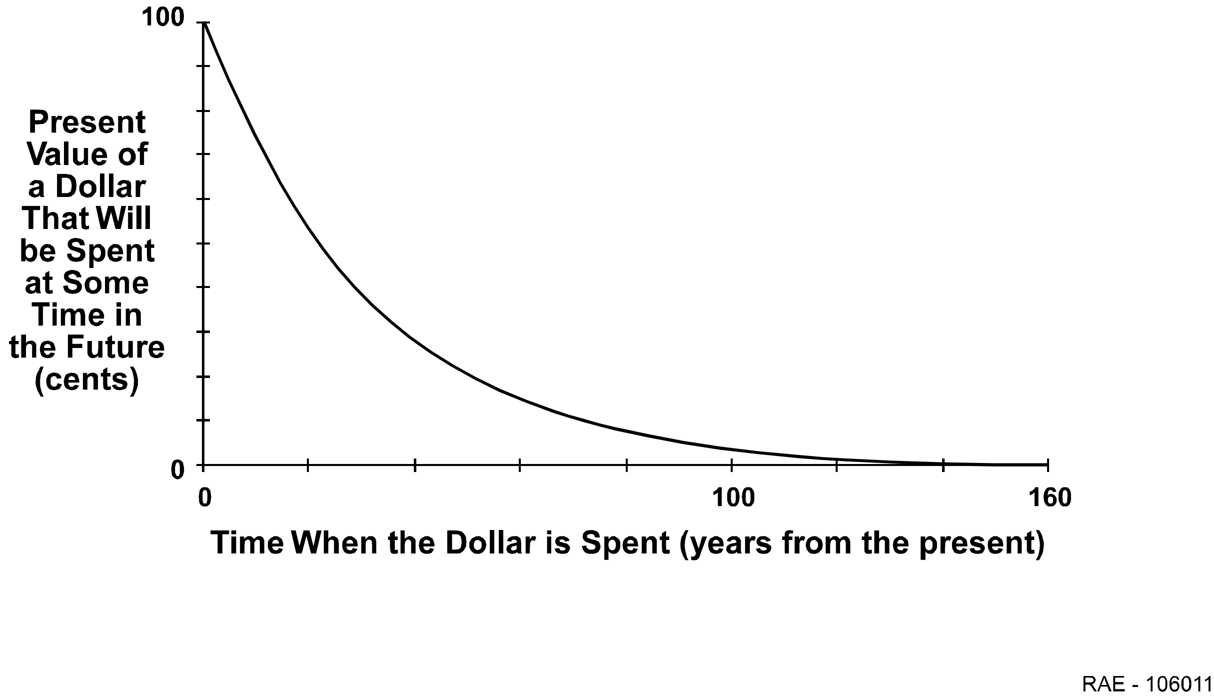

Figure 3-2. Effect of present value analysis.

100 years in the future is equivalent to less than 4 cents now. Beyond about 140 years in the future, the present value of a dollar is less than 1 cent spent now. This illustrates that the present values of the life cycle costs for the two waste management methods being compared will depend largely on the schedules of expenditures in the early years of their existence.

3.2 Present Value Calculation Of Unit Disposal Costs

A unit cost for placing waste in a disposal facility or an assured isolation facility (unit placement cost) is determined using the present values of the facility's life cycle costs and of the revenues required to meet those costs. The revenues required to meet life cycle costs are estimated using the projected annual rates of waste deliveries to the facility and a unit waste placement cost assumed to be constant in real terms (e.g., adjusted for inflation) over the facility's operating life.

The fundamental principal in determining the unit placement cost is the requirement that the present value of the facility=s life cycle costs must equal the present value of revenues. The present value of life cycle costs is estimated as described in Section 3.1.

To calculate the present value unit placement costs, the following procedure was used: The amounts of waste to be emplaced annually were ascertained (see Page 2-3). A normalized present value of the waste revenue was calculated, assuming that one dollar of revenue is received for each cubic foot of waste, at the time the waste is emplaced. The present values of the facility life cycle costs were then divided by the normalized present value of all waste revenues.

Estimates of present value unit disposal costs are provided in Table 4-3.

4. COMPARISON OF PRESENT VALUE LIFE CYCLE COSTS

The present value life cycle costs for the conceptual disposal and assured isolation facilities were calculated using the cost estimates given in Appendix D. The annual costs for the preoperations phase were represented as being the same for each year. As illustrated in Figure 4-1, annual costs for the operations phases were represented as being the same year-by-year over three distinct intervals, based on the three different rates of waste receipt illustrated in Figure 2-1. Annual expenditures for monitoring and maintenance during the institutional control phase for the disposal facility also were assumed to be the same within each of the three distinct intervals for that phase. The annual expenditures for the inspection and preventive maintenance phase for the assured isolation facility were assumed to be the same within each of the two distinct intervals for that phase. The annual costs for each of those intervals reflect the decreasing levels of monitoring and maintenance that are presumed to result from growing confidence in the performance of the two facilities and the decay of radioactivity in the waste.

In the present value calculations, a 7.5-percent annual return on investment was assumed for all costs incurred up to and including the end of waste receipt. For all subsequent costs, the return on investment was assumed to be 6 percent. A 4-percent inflation rate was assumed for all present value calculations.

4.1 Costs for Individual Cases

Figure 4-1 illustrates the annual expenditures for the sets of cases described in Appendix C. It clearly shows the smaller costs associated with the preoperations phase for the assured isolation facility, followed by operations costs that are almost identical to those for the disposal facility. The figure also shows the extra costs required to close the disposal facility at the end of operations.

Table 4-1 lists the present value costs of the cases described in Section 2.4. Sets of present value costs from each phase in the life cycle of a disposal facility or an assured isolation facility can be added to obtain an estimate of the total life cycle cost. Any feasible combinations of cases, as described in Section 2.4, can be used.

4.2 Costs for Selected Combinations of Cases

The present value costs for two particular sets of cases (one set for disposal and one set for assured isolation) are given in Table 4-2. The approximate timing and expenditures for each set of cases are illustrated in Figure 4-1. Table 4-2 shows that, for the sets of cases chosen, the disposal method and assured isolation method of waste management have essentially the same present value life cycle costs. The present value of the preoperations cost for the disposal method is higher than for assured isolation, primarily because of the greater costs of site characterization and licensing. However, there is a greater cost for activities during the operations phase for the assured isolation facility, primarily due to greater construction costs.

The effect that present value analysis has on reducing the relative impact of expenses that occur later in the life cycle can be observed by comparing the relative magnitudes of the same major cost components in Table D-1 with their corresponding present values in Table 4-2. In Case D1A, for example, the present value analysis reduces the preoperations cost for the disposal facility from $74 million in 1996 dollars to a present value of $69 million (about a 7-percent reduction). However, in Case D3, the present value analysis reduces the cost of closure and postclosure from $30 million in 1996 dollars to $9.7 million (about a 68-percent reduction).

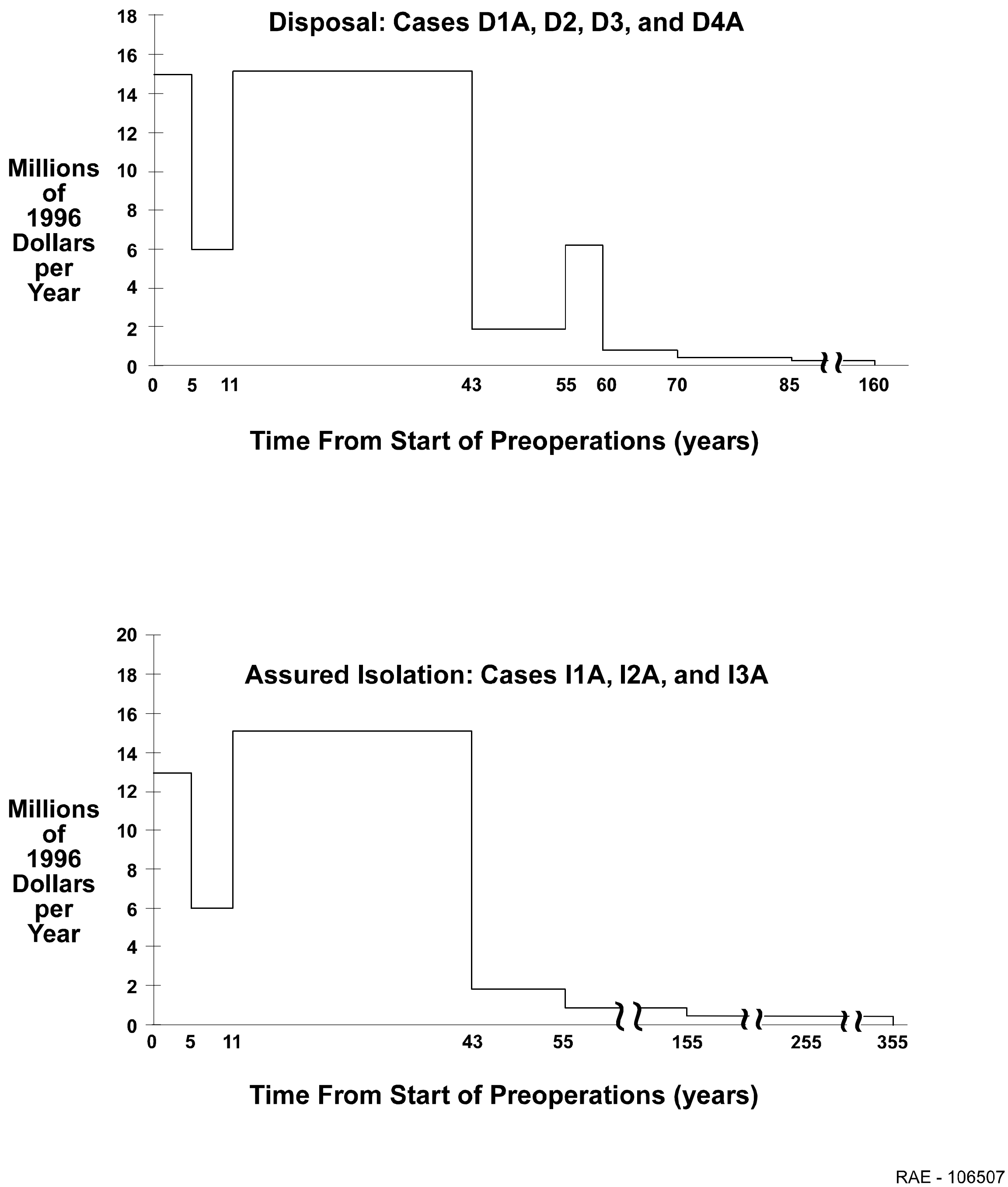

Figure 4-1. Expenditure rates as a function of time; selected cases.

Table 4-1. Present value costs for the cases described in Section 2.4.[a]

DISPOSAL		ASSURED ISOLATION	
5 Years of Preoperations			
D1A (optimistic)	69,000	I1A (no site groundwater characterization)	60,000
D1B (recent experience; one site characterized)	120,000	I1B (limited site groundwater characterization)	64,000
D1C (recent experience; two sites characterized)	140,000	I1C (site characterization comparable to D1A)	70,000
50 Years of Operations			
D2	250,000	I2A (no groundwater monitoring)	260,000
		I2B (groundwater monitoring)	260,000
5 Years of Closure and Postclosure			
D3	9,700	Not applicable	
100 or 300 Years of Institutional Control		300 or 500 Years of Inspection and Preventive Maintenance	
D4A (100 years of institutional control)	5,600	I3A (300 years of I&PM)	15,000
D4B (300 years of institutional control)	7,800	I3B (500 years of I&PM)	15,000

Table 4-2. Present value costs for the set of cases described in Appendix C.

Phase	Disposal Facility (thousands of dollars)		Assured Isolation Facility (thousands of dollars)	
Preoperations	69,000	(Case D1A)	60,000	(Case I1A)
Operations	250,000	(Case D2)	260,000	(Case I2A)
Closure and postclosure	9,700	(Case D3)	---	
Institutional control	5,600	(Case D4A)	---	
Inspection and preventive maintenance	---		15,000	(Case I3A)
Total	340,000[a]		330,000[a]	

a. Total may not equal the sum of the cost elements because of rounding.

4.3 Costs for all Combinations of Cases

As noted in Section 2.4, there are 6 plausible combinations of cases, or scenarios, for disposal and 6 for assured isolation. Table 4-3 shows constant 1996 dollar life cycle costs, present value life cycle costs, and present value unit costs for the 12 plausible combinations of cases (i.e., scenarios) analyzed. For convenience, the definitions of the cases in the tables, originally given in Section 2.4, are repeated at the end of this chapter.

Table 4-3 is divided into three sections by dashed lines. The scenarios in each section are identical except for the preoperations case. The table shows that the present value life cycle costs for the plausible combinations range from $330 million for assured isolation to $410 million for disposal. The unit placement costs are directly proportional to the present value life cycle costs and scale accordingly. Life cycle costs for disposal are close to those for assured isolation only when the very low disposal preoperations costs in Case D1A are used. Whenever one of the other two disposal preoperations cases is used, disposal has a higher present value life cycle cost than assured isolation.

The largest life cycle costs for disposal involve preoperations Cases D1B or D1C, both of which incorporate costs based on recent experience in siting and developing disposal facilities, resulting in very high preoperations costs. Present value calculations weight costs at the beginning of the life cycle very heavily; consequently, the high experience-based costs for disposal preoperations cause disposal to have a higher present value life cycle cost. The lowest estimates for present value life cycle costs for both disposal and isolation, $340M and $330M respectively , occur when the cases with the lowest preoperations costs are used.

Table 4-3. Comparison of life cycle costs and unit costs.

DISPOSAL				ASSURED ISOLATION			
Scenario	**Thousands of Constant (1996) Dollars**	**Present Value (thousands of dollars)**	**Present Value Unit Placement Cost (dollars per cubic foot)**	**Scenario**	**Thousands of Constant (1996) Dollars**	**Present Value (thousands of dollars)**	**Present Value Unit Placement Cost (dollars per cubic foot)**
D1A+D2+D3+D4A	710,000	340,000	520	I1A+I2A+I3A	810,000	330,000	510
D1A+D2+D3+D4B	780,000	340,000	520	I1A+I2A+I3B	880,000	330,000	510
D1B+D2+D3+D4A	760,000	390,000	590	I1B+I2B+I3A	820,000	340,000	520
D1B+D2+D3+D4B	830,000	390,000	590	I1B+I2B+I3B	900,000	340,000	520
D1C+D2+D3+D4A	780,000	410,000	620	I1C+I2B+I3A	830,000	350,000	530
D1C+D2+D3+D4B	850,000	410,000	630	I1C+I2B+I3B	900,000	350,000	530

When the preoperations costs used in the analyses for assured isolation are compared to those used for disposal, it can be seen that the former are generally much lower than the latter. Note that the highest preoperations cost for assured isolation (Case I1C) is equal to the lowest preoperations cost for disposal (Case D1A).

The effect of present value calculations on the importance of costs of activities that occur late in the life cycle is underscored by the fact that almost all of the life cycle costs in Table 4-3 occur as pairs of identical costs (when rounded to two significant digits). The two members of each pair differ only in the duration of the institutional control phase (for disposal) or of the inspection and preventive maintenance phase (for assured isolation). The fact that the different durations of those phases (which occur late in the life cycle) have little or no impact on the present value life cycle cost illustrates how the present value calculation greatly reduces the significance of such distant future expenditures. When the cost for inspection and preventive maintenance for assured isolation is expressed in 1996 dollars, it is about three or four times the cost in 1996 dollars for preoperations for assured isolation (see Table D-1). Table 4-2 shows that when that cost is converted to present value cost, it becomes only a fraction of the present value cost of preoperations.

The following describes the cases analyzed:

DISPOSAL

<u>Preoperations Phase</u>

Case D1A: This case is based on the methods used in NY 1995 and RAE 1992. The costs tend to be optimistically low compared to recent experience.

Case D1B: This case is based on an estimate of the average recent experience for preoperations costs in the U.S. Full characterization of a single site is assumed.

Case D1C: This case is also based on recent experience, but with full characterization of two sites.

<u>Operations Phase</u>

Case D2: This case represents operations at the disposal facility.

<u>Closure and Postclosure Phase</u>

Case D3: This case represents closure and postclosure activities at the disposal facility.

<u>Institutional Control Phase</u>

Case D4A: This case represents institutional control lasting 100 years.

Case D4B: This case represents institutional control lasting 300 years.

ASSURED ISOLATION

Preoperations Phase

Case I1A: This case represents preoperations activities that do not include site characterization because the assured isolation inspection system is designed to preclude release of contamination to the site.

Case I1B: This case is the same as Case I1A, except that limited or confirmatory drilling and groundwater characterization at the site are added.

Case I1C: In this case, the costs for several preoperations cost elements from Case D1A are used for the site development and for the licensing and permitting cost elements. They include costs for site development, environmental assessment and license application, licensing, and permits. This case represents a full site characterization and licensing process comparable to that for a disposal facility, as represented by the preoperations cost in Case D1A. (The licensing process, however, need not depend on site characteristics.)

Operations Phase

Case I2A: This case represents operations at the assured isolation facility, without groundwater monitoring.

Case I2B: This case is the same as for Case I2A, except that a cost for groundwater monitoring is added.

Inspection and Preventive Maintenance Phase

Case I3A: The case represents inspection and preventive maintenance with cost estimation ending 300 years after the end of operations.

Case I3B: This case represents inspection and preventive maintenance with cost estimation ending 500 years after the end of operations.

5. REFERENCES

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